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Final Report: Atmospheric Probe Model:
Construction and Wind Tunnel Tests

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ATMOSPHERIC PROBE MODEL WIND TUNNEL TESTS

SUMMARY

The material contained in this document represents a summary of the results of a low speed wind tunnel test program to determine the performance of an atmospheric probe at low speed. The probe configuration tested consists of a 2/3 scale model constructed from a combination of hard maple wood and aluminum stock. The model design includes approximately 130 surface static pressure taps. Additional hardware incorporated in the baseline model provides a mechanism for simulating external and internal trailing edge split flaps for probe flow control. Test matrix parameters include probe side slip angle, external/internal split flap deflection angle, and trip strip applications. Test output database includes surface pressure distributions on both inner and outer annular wings and probe center line velocity distributions from forward probe to aft probe locations.

INTRODUCTION

The 2/3 scale atmospheric probe model geometry consists of two concentric annular wings as depicted in Figure 1. The inner and outer wings are attached by means of an interior strut generated by extruding a symmetric airfoil aligned with the longitudinal axis. The strut extends beyond the outer annular wing to the wind tunnel top wall where the model is attached. Figure 2. depicts a cross sectional view with major dimensions associated with the scaled configuration.

WIND TUNNEL MODEL

Model Description

Model Construction Technique

The probe model was constructed by milling 21 2-D facets for each of the outer and inner annular wings. Each facet contained compound angular sides such that when assembled the outer and inner wing airfoils formed 360° closed annular surfaces at the design angles-of-attack. Facet widths were adjusted to provide the specified values for the diameters of each annular wing.

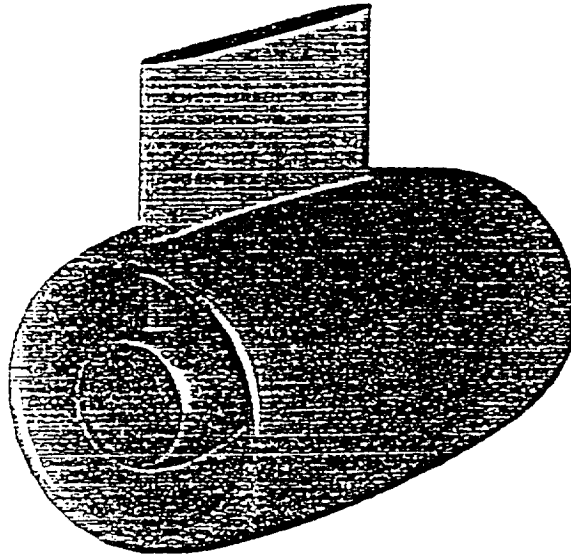


Figure 1. Test Configuration Pictorial View of Probe

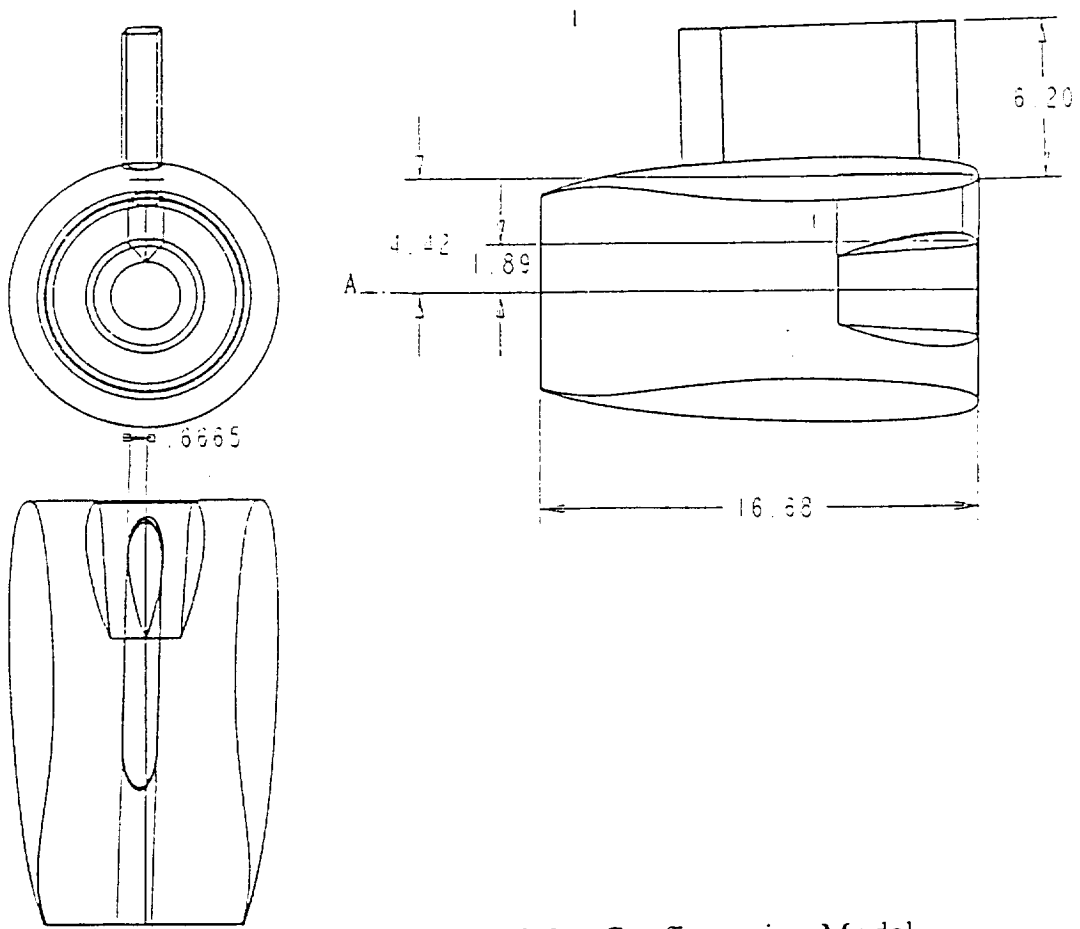


Figure 2. Scaled 3-View of Test Configuration Model

Figure 3. represents a pictorial view of the outer and inner annular wings depicting each of the 21 individual facets. Figure 4. depicts a slice view with the inner and outer wing profiles in perspective. Figure 5. provides an orthographic profile of the probe geometry resulting from a cutting plane intersecting the probe through the longitudinal axis. The attachment pylon used to connect the inner and outer annular wings, and to attach the probe to the wind tunnel wall is not included in Figures 3-5.

Material used in the construction of wing facets consists of hard maple, a material that has good machining qualities. One facet for each the outer and inner wings was constructed from 6061-T6 aluminum providing a firm surface in which static pressure ports were drilled. Regions within the centers of all facets were removed to accommodate pressure tubes extending from each surface static port, through the attachment pylon, and through the wind tunnel wall to the instrumentation rack. Facets for each wing were combined using a combination of glue at each joint and an internal metallic band. Figure 7. depicts the actual model mounted in the ISU low speed wind tunnel.

Split flap components for alternate facets of the outer annular wing were constructed from 0.04 inch aluminum plate cut to the width of the facet. Flap deflection angle was set by simply bending the plate at the flap hinge line. Flap chord is 1.5 inches and each flap segment is attached to the individual facets using aluminum tape. Flap trailing edges are aligned with the wing trailing edge. Flap segments are included for both the outer and inner surfaces of the external (outside) annular wing. Figures 8. and 9. incorporate film prints depicting the outer and inner surface flap segments for the model, respectively

Model Instrumentation

Model instrumentation included both scanivalve and PSI scanner systems to measure static pressures along both the inner and outer surfaces for one facet in each the outer and inner annular wings. Static ports were located along the airfoil surfaces with surface separations of between 0.1 and 0.4 inches with the closer spacing reserved for leading and trailing edge locations. The static ports (approximately 100) have a 0.025 inch diameter. A traversing pitot tube was used to acquire dynamic pressure at 0.25 inch intervals along the centerline axis of the probe from the leading of the probe to near the trailing edge of the outer annular wing.

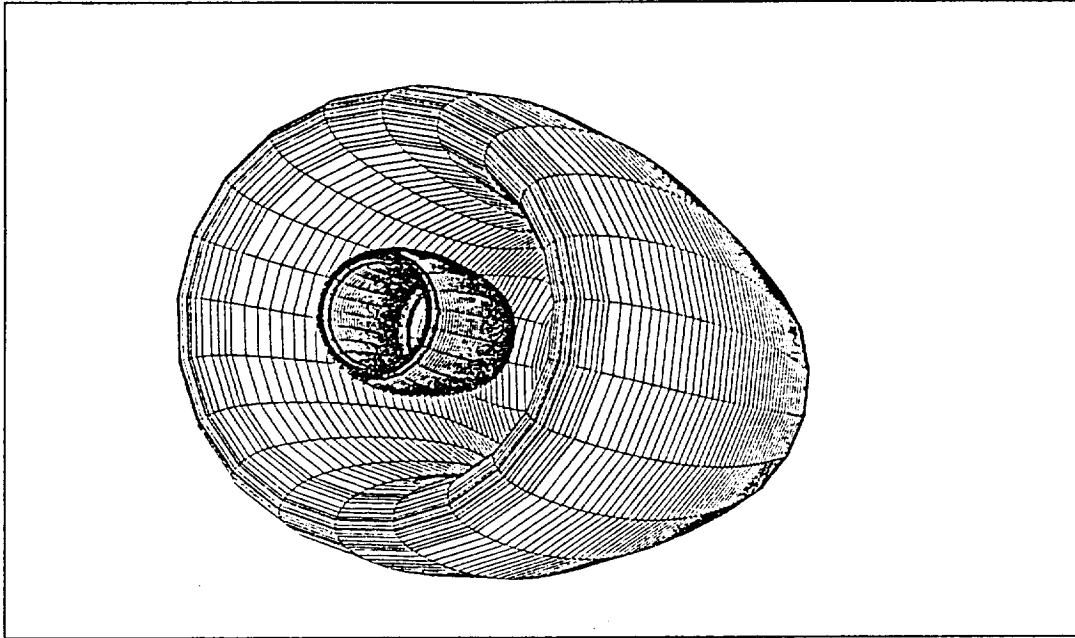


Figure 3. Pictorial view of inner and outer annular wings depicting individual facets. Attachment pylon not shown.

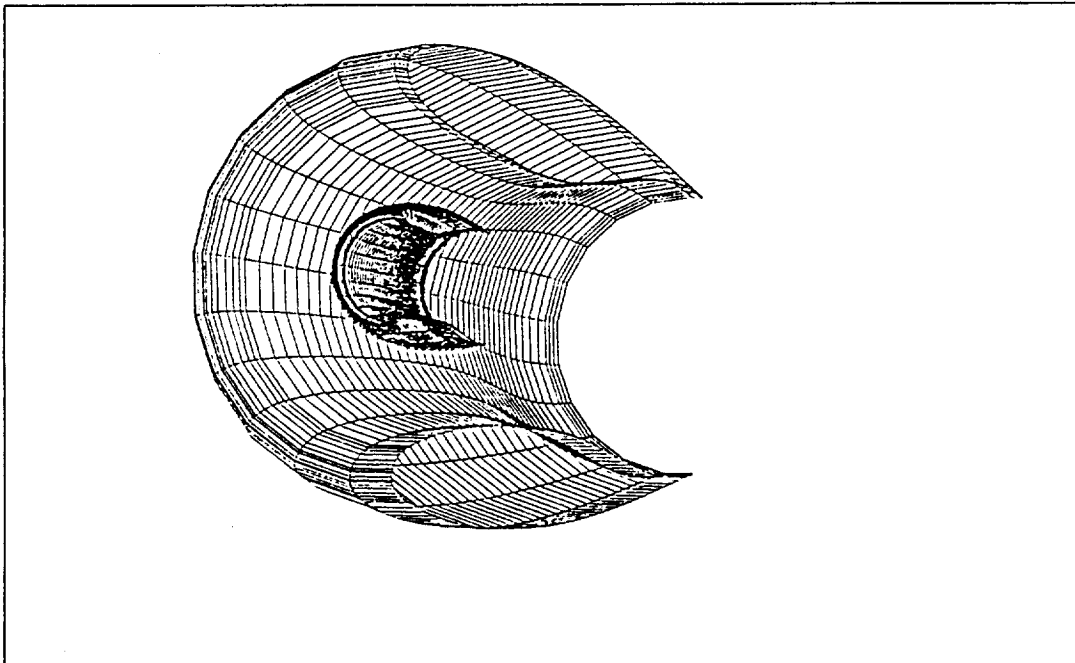


Figure 4. Sliced pictorial view of probe showing annular wing profiles.

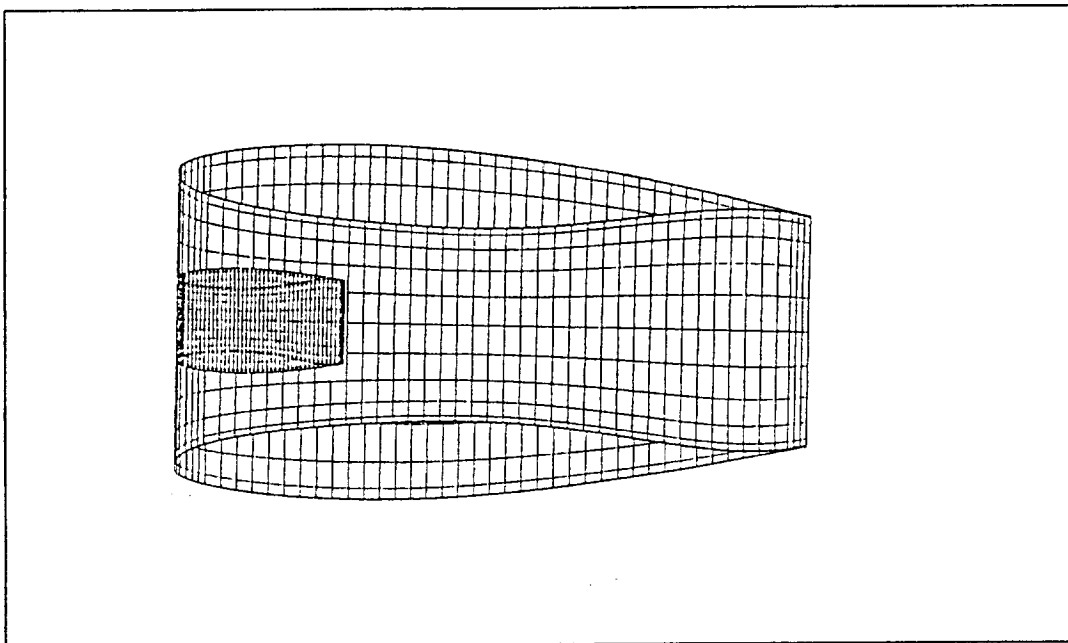


Figure 5. Orthographic profile view of inner and outer annular wings. Attachment pylon not shown.

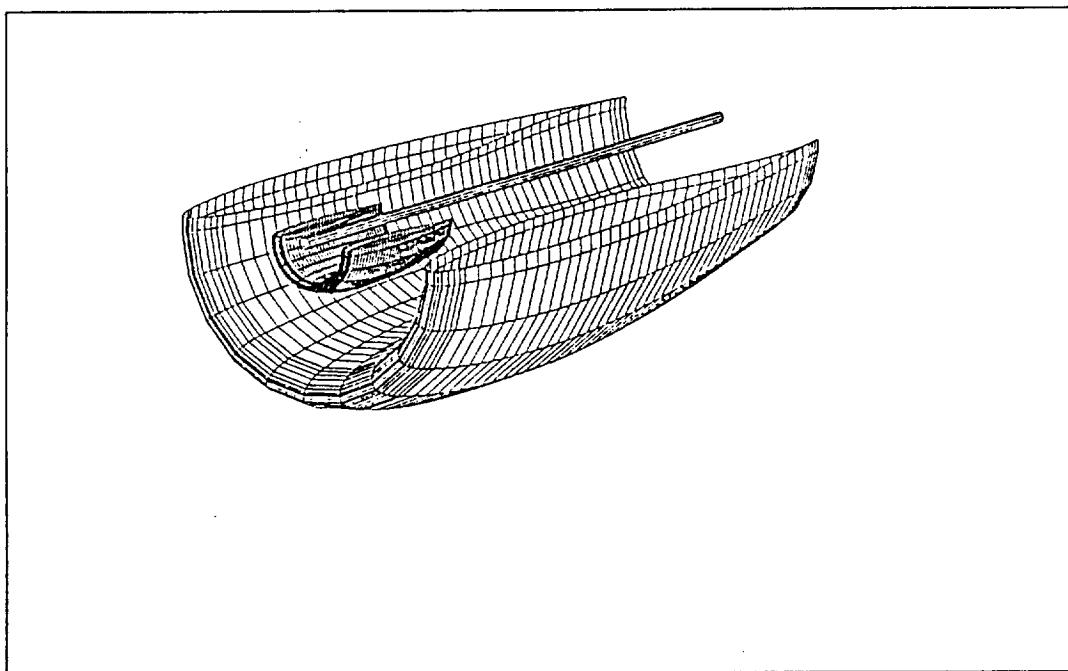


Figure 6. Sliced pictorial view of probe showing centerline tube enclosing the region along which velocity ratio profiles are acquired with a pitot tube.

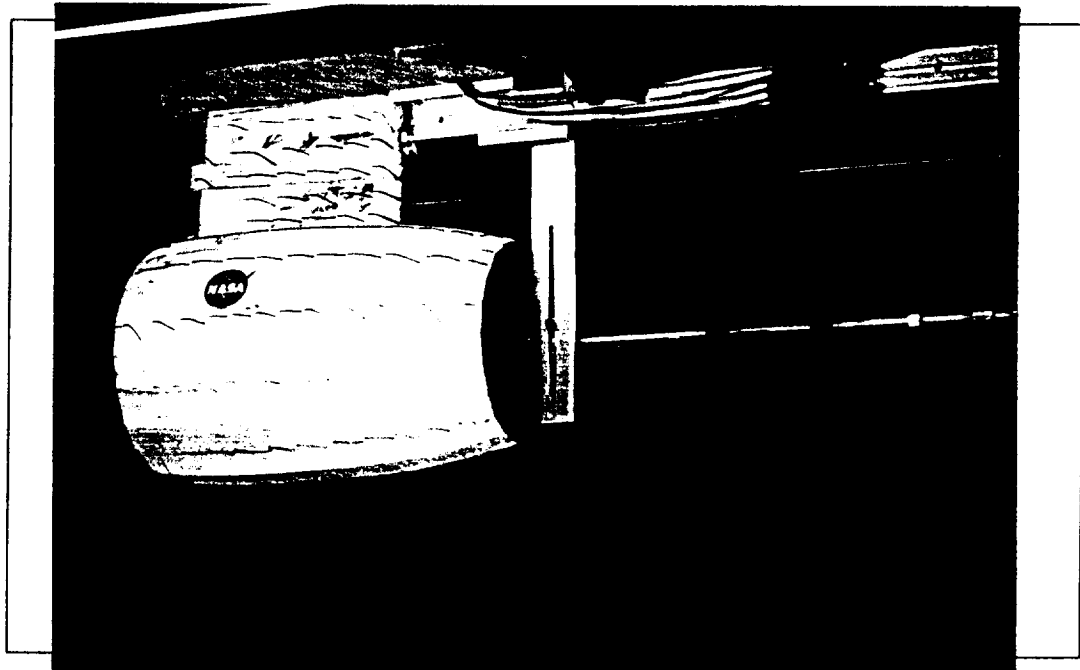


Figure 7. 2/3 Scale hardwood model probe mounted in the ISU low speed wind tunnel.

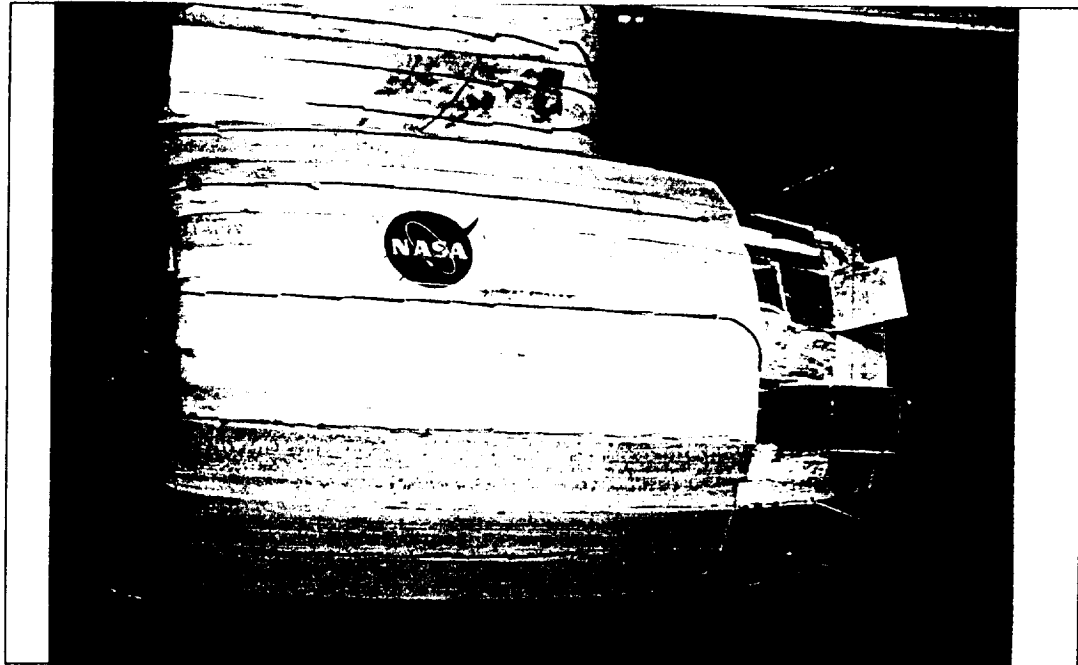


Figure 8. 2/3 Scale model probe with outer surface split flap segments mounted on alternate model body facets. Flap are shown in the deflected state.

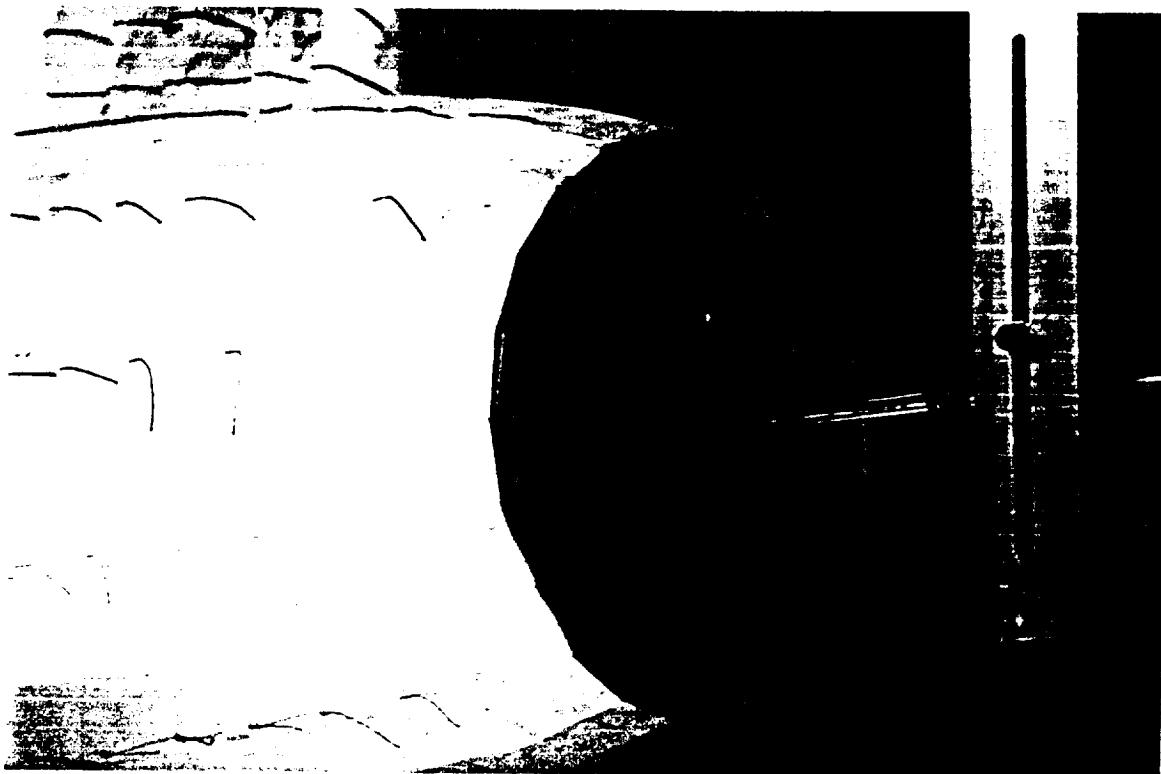


Figure 9. 2/3 Scale model probe with inner surface flap segments on alternate body surface facets. Flap segments are shown in a deflected condition

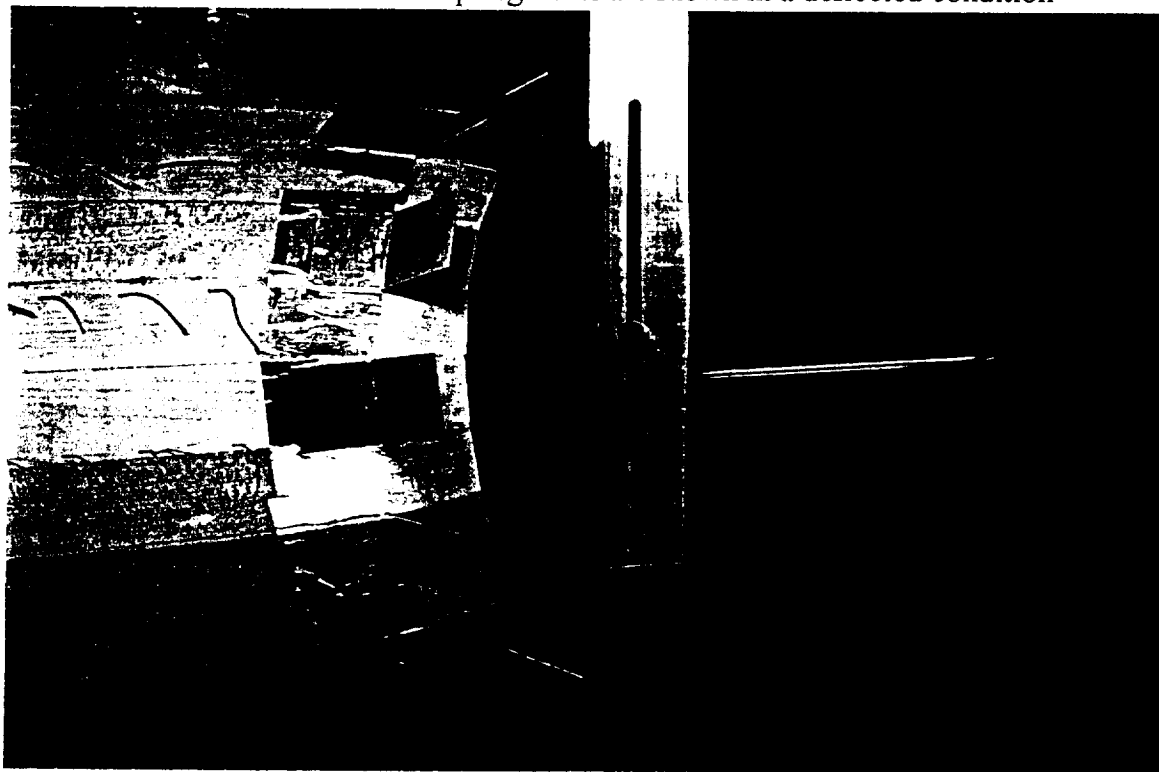


Figure 10. 2/3 Scale model probe with outer surface flap segments on alternate body surface facets. Flap segments are shown in a deflected condition.

Static Port Locations

Static ports were incorporated in one facet of each annular wing. A total of 70 and 33 ports were used for the outer and inner wing airfoil profile distributions, respectively. Locations for these ports in terms of the non-dimensional position along the airfoil chord are given in the Table 1.

Outer Wing Surface Port Locations (x/c)					Inner Wing Surface Port Locations (x/c)	
1	2	3	4	5	1	2
0.9953	0.6002	0.0627	0.2087	0.9277	0.8839	0.0028
0.9722	0.5656	0.0505	0.2445	0.9855	0.8348	0.0154
0.9601	0.5339	0.0388	0.3167		0.7911	0.0320
0.9435	0.4928	0.0266	0.3525		0.7564	0.0488
0.9169	0.4551	0.0152	0.3884		0.7354	0.0865
0.8576	0.4201	0.0088	0.4256		0.6586	0.1915
0.8465	0.3844	0.0009	0.4948		0.5698	0.2652
0.8375	0.3481	0.0080	0.5313		0.5126	0.4224
0.8318	0.3118	0.0199	0.6015		0.3590	0.5006
0.8159	0.2754	0.0342	0.6373		0.2864	0.5743
0.8027	0.2403	0.0425	0.6741		0.2167	0.6361
0.7903	0.2032	0.0543	0.7101		0.1468	0.7288
0.7641	0.1812	0.0651	0.7404		0.1155	0.7735
0.7423	0.1526	0.0787	0.7650		0.1001	0.8332
0.6903	0.1332	0.1019	0.7873		0.0937	0.8944
0.6727	0.1102	0.1252	0.8104		0.0703	0.9095
0.6362	0.0859	0.1733	0.9034		0.0190	

Table 1. Non-dimensional Static Port Locations for Inner and Outer Annular Wings

WIND TUNNEL TESTS

Wind Tunnel

The wind tunnel used in the data acquisition process was the ISU Low Turbulence Open Circuit Tunnel with a 3-D test section of approximately 36 inch x 30 inch cross section.

Test Matrix

Parameters/conditions included in the wind tunnel test matrix are as follows:

<u>Parameter</u>	<u>Values Tested</u>
Test section dynamic pressure	q @ 220 fps
Model side slip angle	0°, 1.0°, 3.0°, 5.0°
External flaps	0°, 15°, 30°, 45°
Internal flaps	15°
Boundary layer trips	Both annular wings

Data Acquired

Data recorded during wind tunnel runs for combinations of the parameters in the test matrix include surface pressures at all surface ports on the inner and outer wings (approximately 100 ports), dynamic pressures along the centerline axis of the probe (approximately 70 positions), and other standard tunnel outputs defining test conditions.

WIND TUNNEL TEST RESULTS

Plots depicting the impact of yaw angle, split flap deflection, and boundary layer trip on surface pressure distributions of the inner and outer annular wings and probe centerline velocity ratio distribution are contained in Appendix A. A series of 3 tests at a test section velocity of 220 ft/sec was conducted on each probe configuration to demonstrate repeatability of results.

The pressure distribution plots are normalized with respect to the outer annular wing chord. Both the inner and outer annular distributions are depicted on the same plot. In all cases, the solid line represents the outer surface of each annular wing and the dashed line the inner surface.

The centerline velocity ratio plots are not normalized. Distance along the centerline of the probe are given in inches from the leading edge of the probe.

Split flaps were tested on both the inside and outside surfaces of the outer annular wing. Flaps were not included on the inner annular wing. In the material that follows, flap settings that are not identified with respect to inside or outside flap configurations are outside flaps.

The following list identifies the probe configurations associated with the plots contained in Appendix A.

<u>Figure No.</u>	<u>Plot Type</u>	<u>Split Flap Settings</u>	<u>Yaw Angle</u>	<u>BL Trip</u>	<u>Test No.</u>
A-1	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	0°	none	1
A-1a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	0°	none	1
A-2	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	0°	none	2
A-2a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	0°	none	2
A-3	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	0°	none	3
A-3a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	0°	none	3
A-4	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	1°	none	1
A-4a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	1°	none	1
A-5	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	1°	none	2
A-5a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	1°	none	2
A-6	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	1°	none	3
A-6a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	1°	none	3
A-7	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	3°	none	1
A-7a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	3°	none	1
A-8	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	3°	none	2
A-8a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	3°	none	2
A-9	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	3°	none	3
A-9a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	3°	none	3
A-10	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	5°	none	1
A-10a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	5°	none	1
A-11	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	5°	none	2
A-11a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	5°	none	2
A-12	C_p vs x/c	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	5°	none	3
A-12a	V/V_{ts}	$0^\circ, 15^\circ, 30^\circ, 45^\circ$	5°	none	3
A-13	C_p vs x/c	15°	$3^\circ, 5^\circ$	trip on	1
A-13a	V/V_{ts}	15°	$3^\circ, 5^\circ$	trip on	1
A-14	C_p vs x/c	15°	$3^\circ, 5^\circ$	trip on	2
A-14a	V/V_{ts}	15°	$3^\circ, 5^\circ$	trip on	2

<u>Figure No.</u>	<u>Plot Type</u>	<u>Split Flap Settings</u>	<u>Yaw Angle</u>	<u>BL Trip</u>	<u>Test No.</u>
A-15	C_p vs x/c	15°	$3^\circ, 5^\circ$	trip on	3
A-15a	V/V_{ts}	15°	$3^\circ, 5^\circ$	trip on	3
A-16	C_p vs x/c	15° (inside & outside)	$3^\circ, 5^\circ$	trip on	1
A-16a	V/V_{ts}	15° (inside & outside)	$3^\circ, 5^\circ$	trip on	1
A-17	C_p vs x/c	15° (inside & outside)	$3^\circ, 5^\circ$	trip on	2
A-17a	V/V_{ts}	15° (inside & outside)	$3^\circ, 5^\circ$	trip on	2
A-18	C_p vs x/c	15° (inside & outside)	$3^\circ, 5^\circ$	trip on	3
A-18a	V/V_{ts}	15° (inside & outside)	$3^\circ, 5^\circ$	trip on	3

Note: V_{ts} represents test section velocity

CONCLUSIONS

The results indicate that the probe centerline velocity ratio is minimum at an interior point approximately 2 inches from the leading edge of the probe. The magnitude of the minimum centerline velocity ratio is about 0.62 for the zero flap deflection case. Outside surface flap deflections on the outer annular wing tend to degrade (increase) the minimum velocity ratio. This is caused by a decrease in outer wing circulation. On the other hand, inside surface flap deflections on the outer annular wing tend to improve (decrease) the minimum centerline velocity ratio. The velocity ratio dropped to slightly below the 0.6 mark for the 15° inside flap deflection case. Hence, it would appear that inside surface flap deflections tend to increase the outer annular wing circulation.

Yaw angle and boundary layer trips appear to have little impact on the centerline velocity ratio.

In all cases, the surface pressure distributions on both the inner and outer annular wings appear to be quite normal. That is, they behave much the same as standard airfoils in lifting situations.

APPENDIX – A

Surface Pressure Distribution Plots for Inner and Outer Annular Wings
Probe Centerline Velocity Ratio Plots

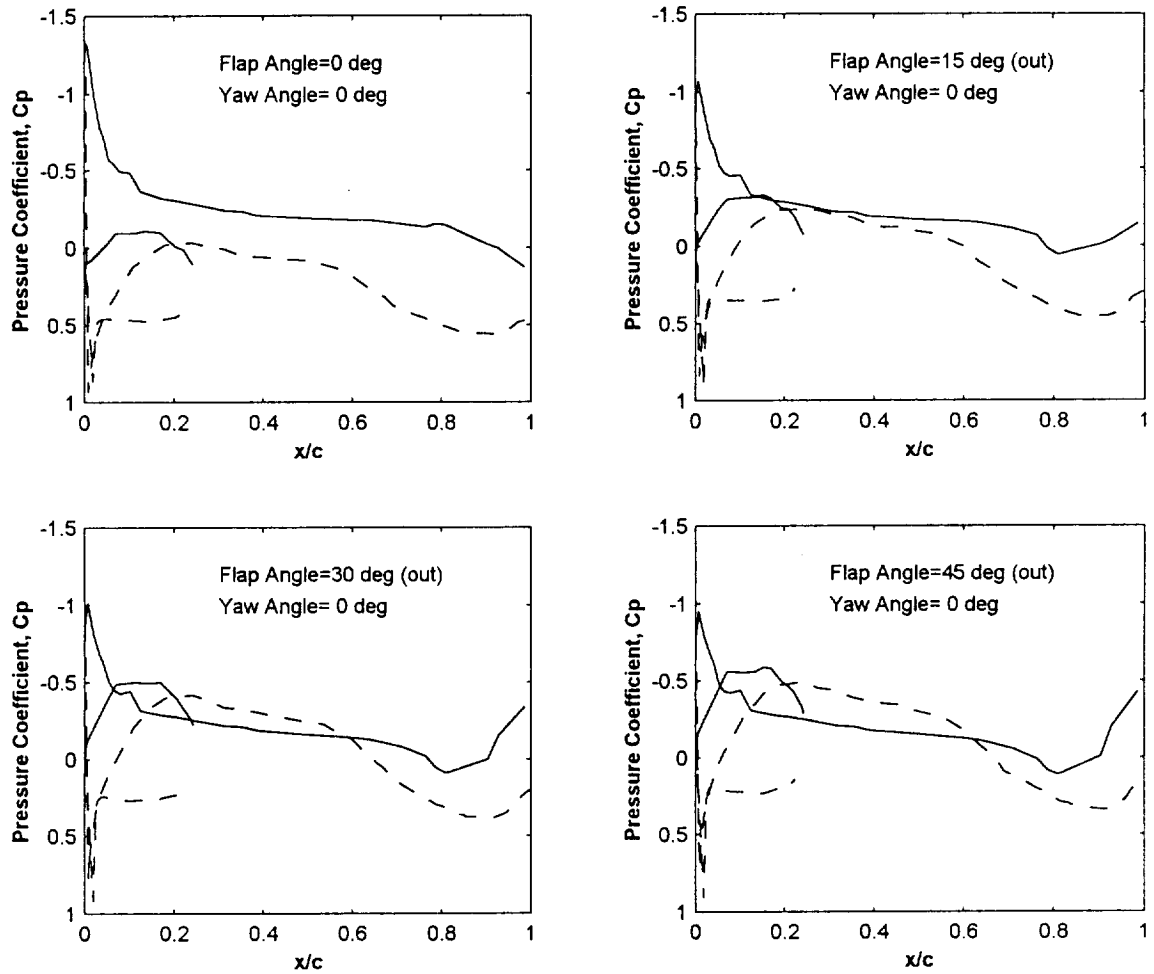


Figure A-1. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 0 deg
 Test #1, Test Section Velocity 220 ft/sec

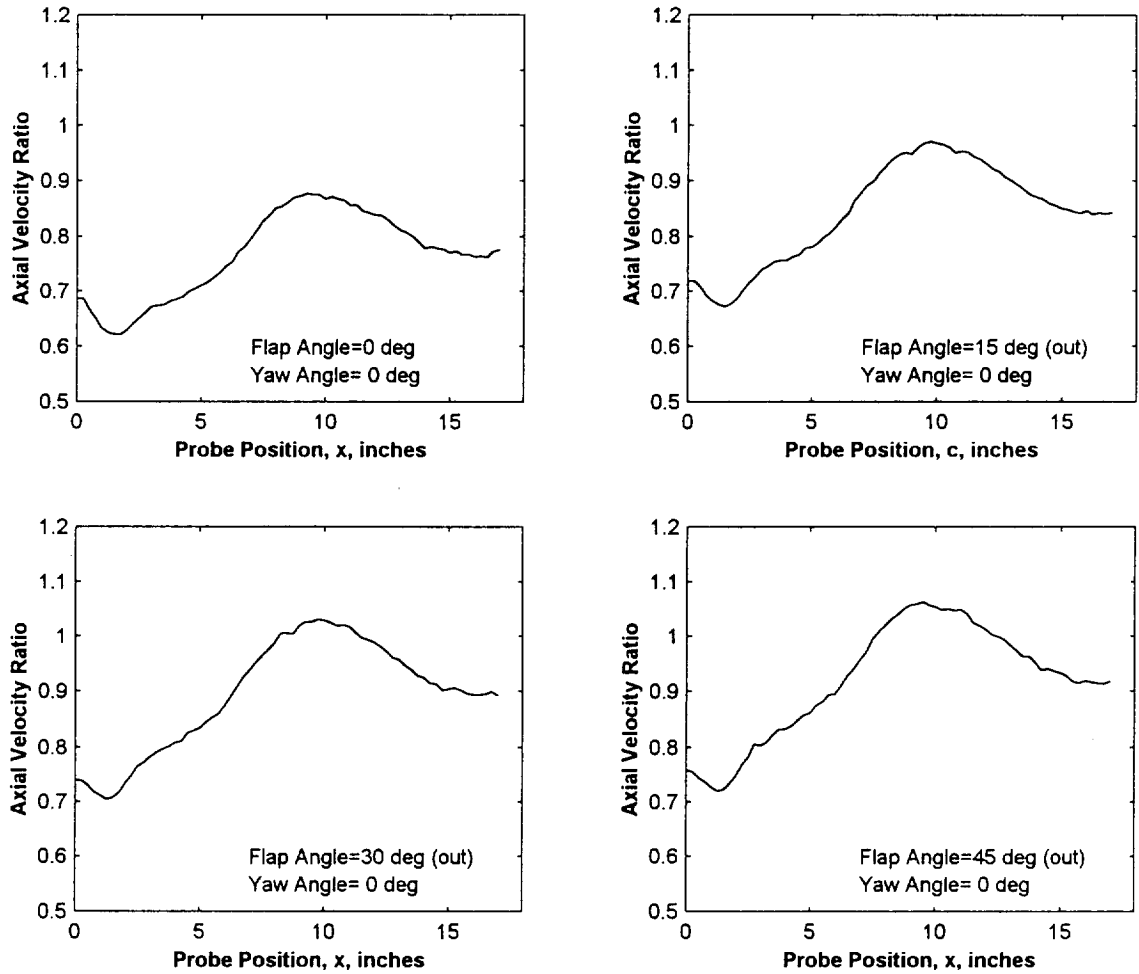


Figure A-1a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 0 deg
 Test #1, Test Section Velocity 220 ft/sec

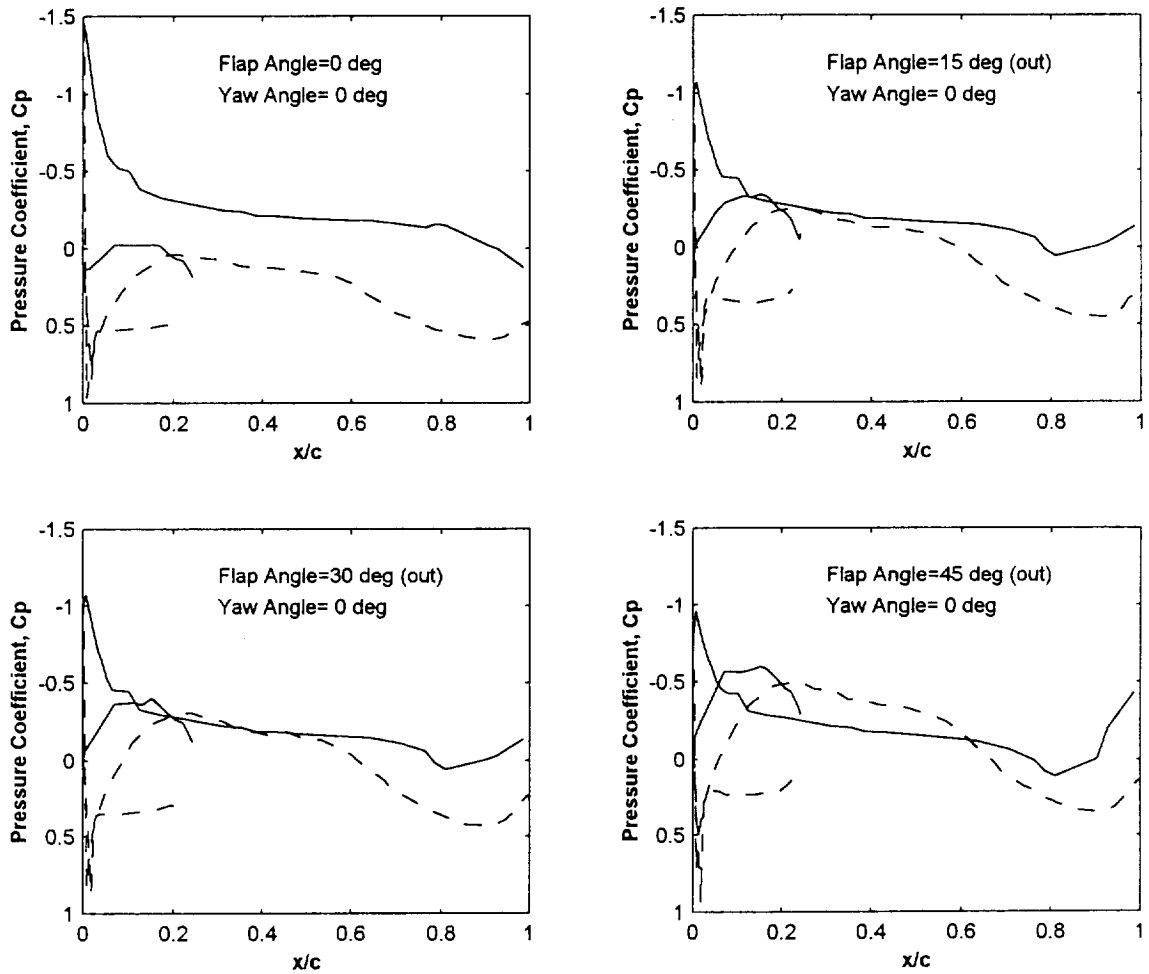


Figure A-2. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 0 deg
 Test #2, Test Section Velocity 220 ft/sec

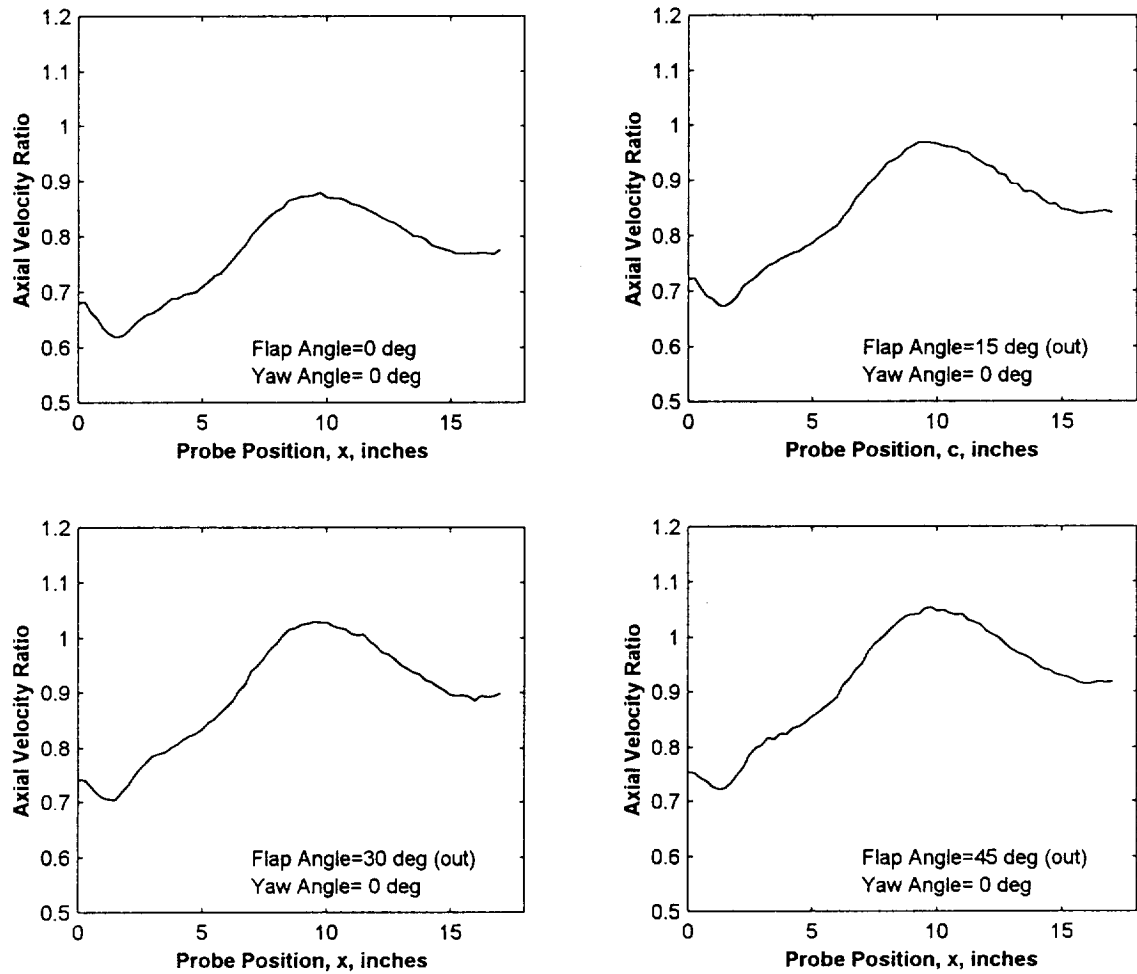


Figure A-2a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 0 deg
 Test #2, Test Section Velocity 220 ft/sec

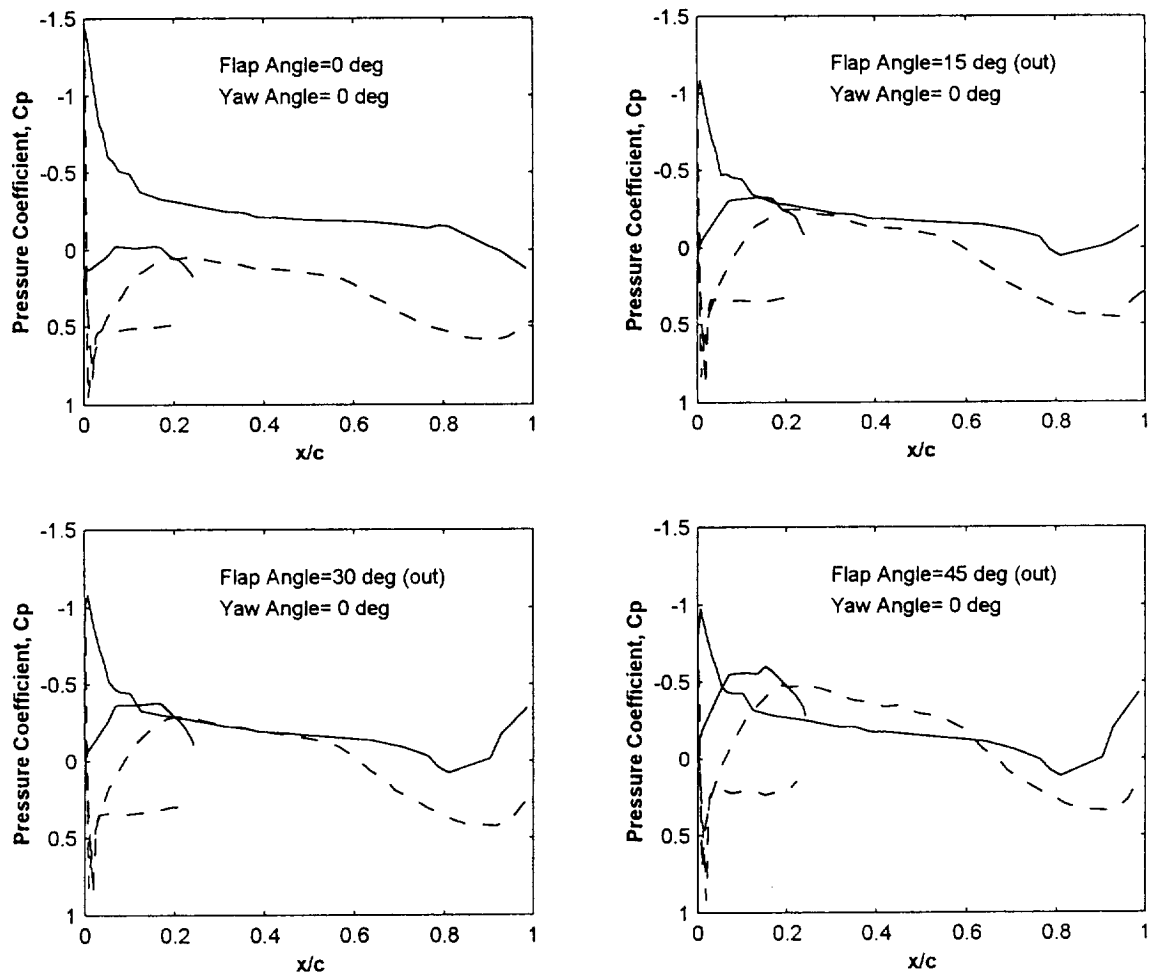


Figure A-3. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 0 deg
Test #3, Test Section Velocity 220 ft/sec

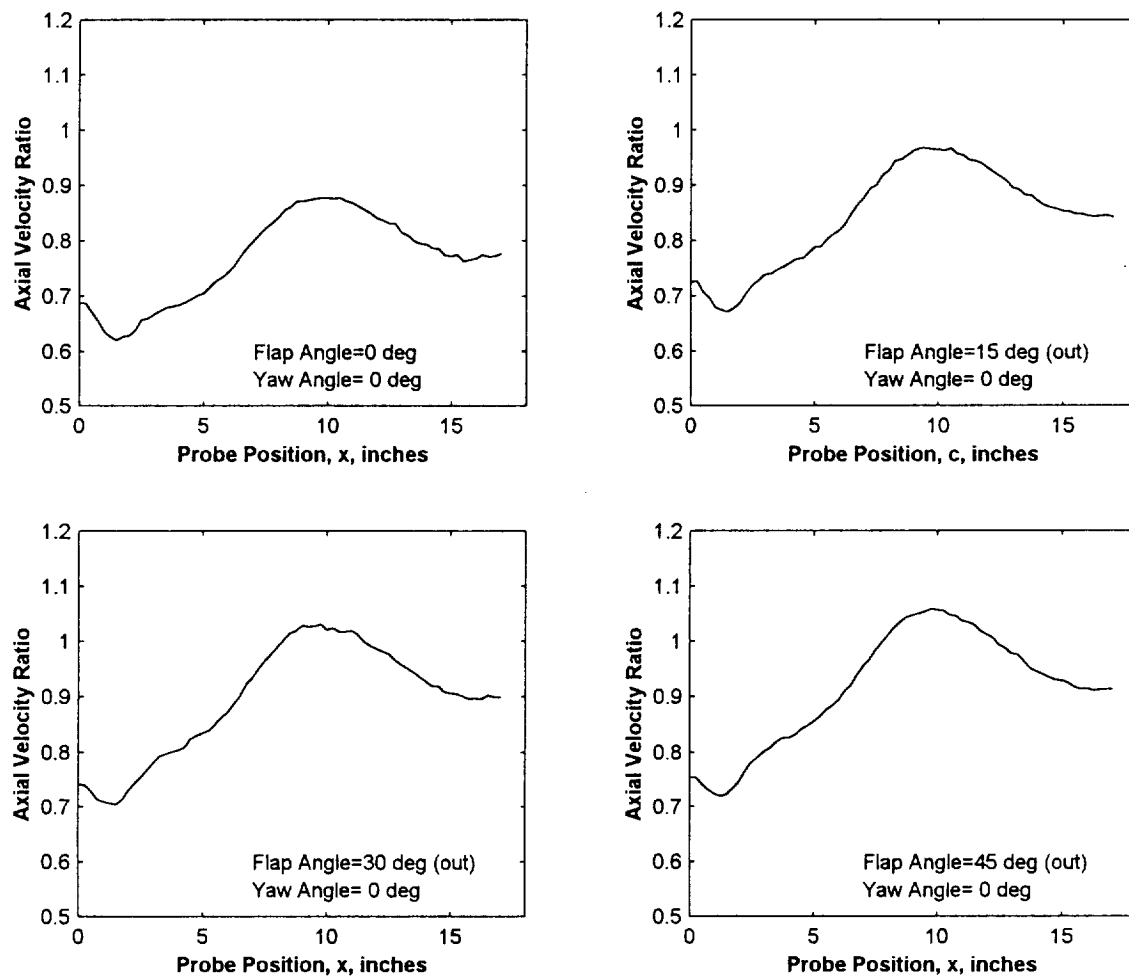


Figure A-3a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 0 deg
 Test #3, Test Section Velocity 220 ft/sec

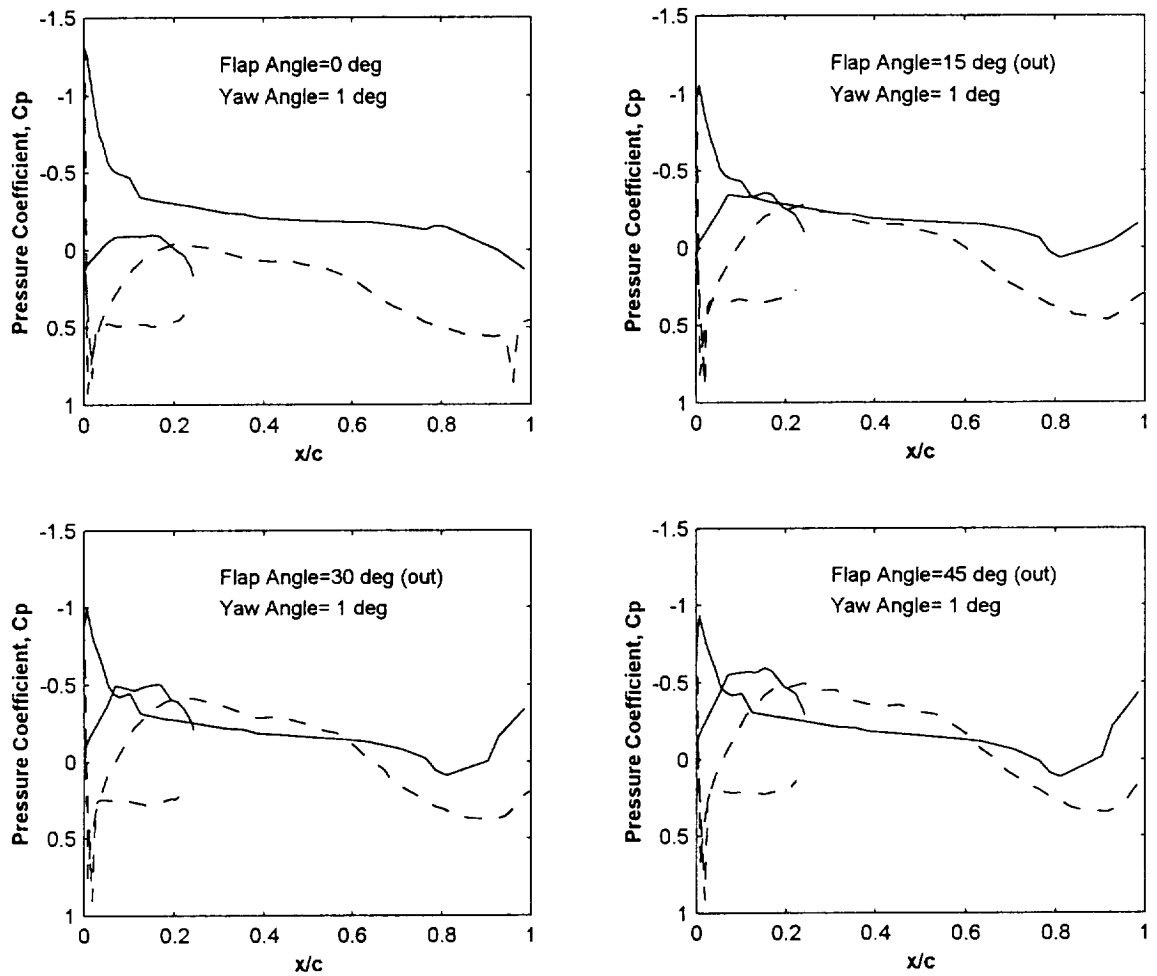


Figure A-4. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 1 deg
Test #1, Test Section Velocity 220 ft/sec

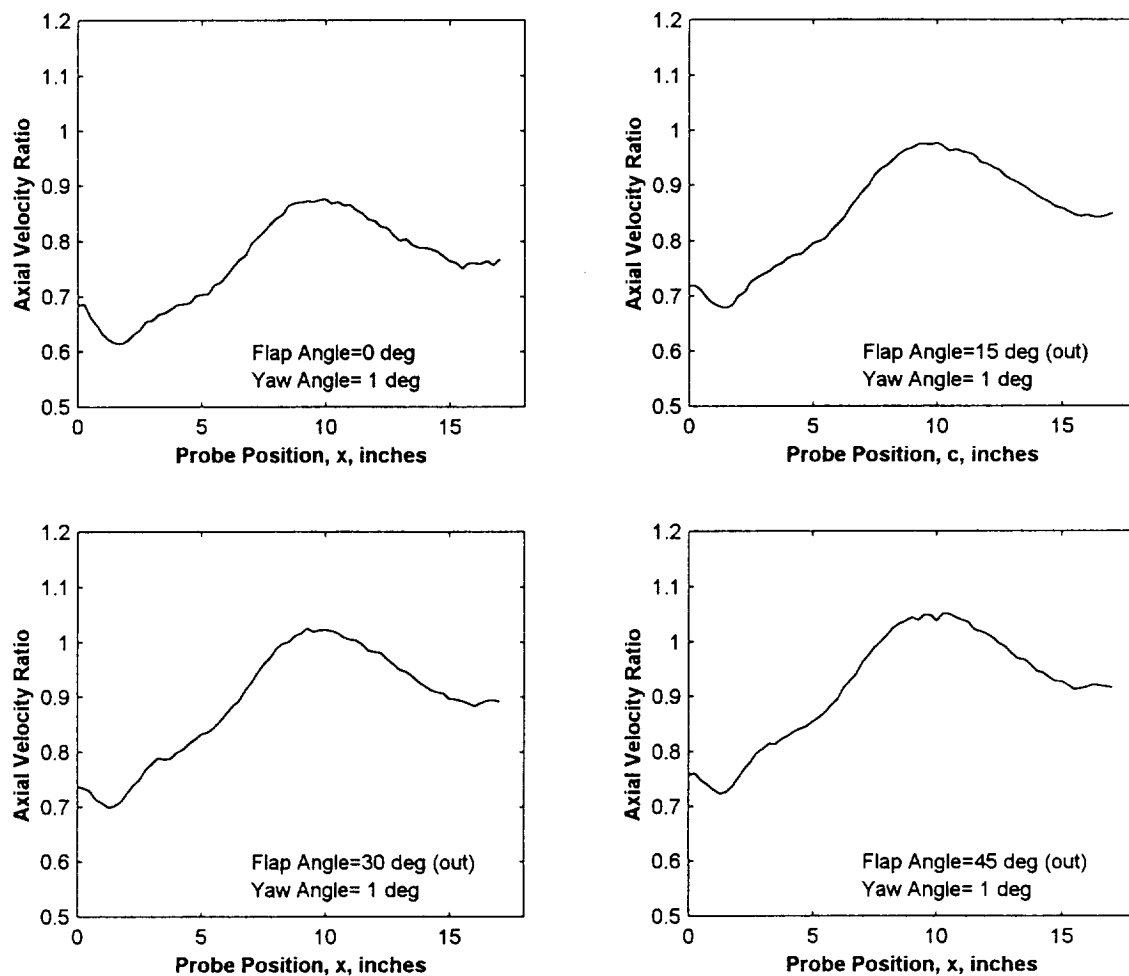


Figure A-4a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 1 deg
 Test #1, Test Section Velocity 220 ft/sec

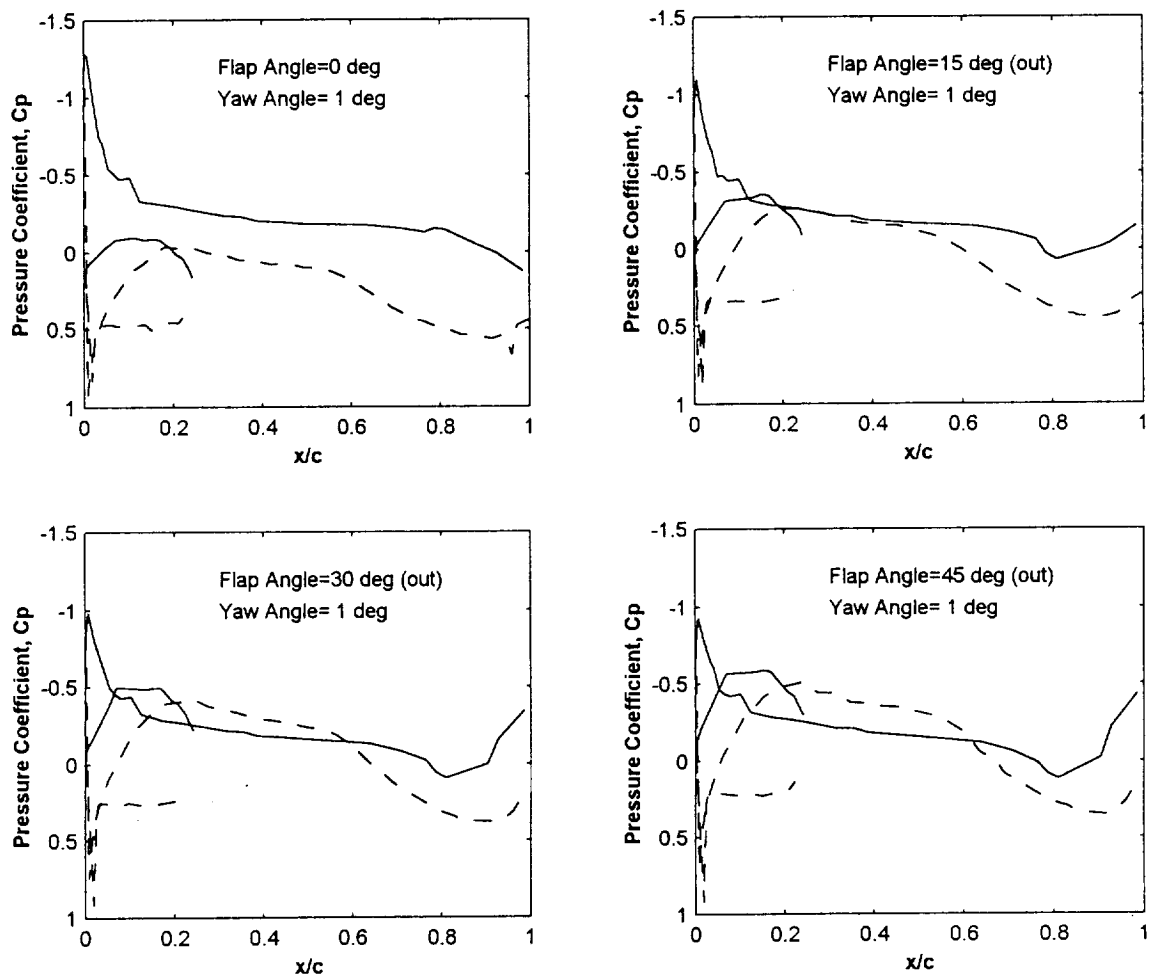


Figure A-5. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 1 deg
 Test #2, Test Section Velocity 220 ft/sec

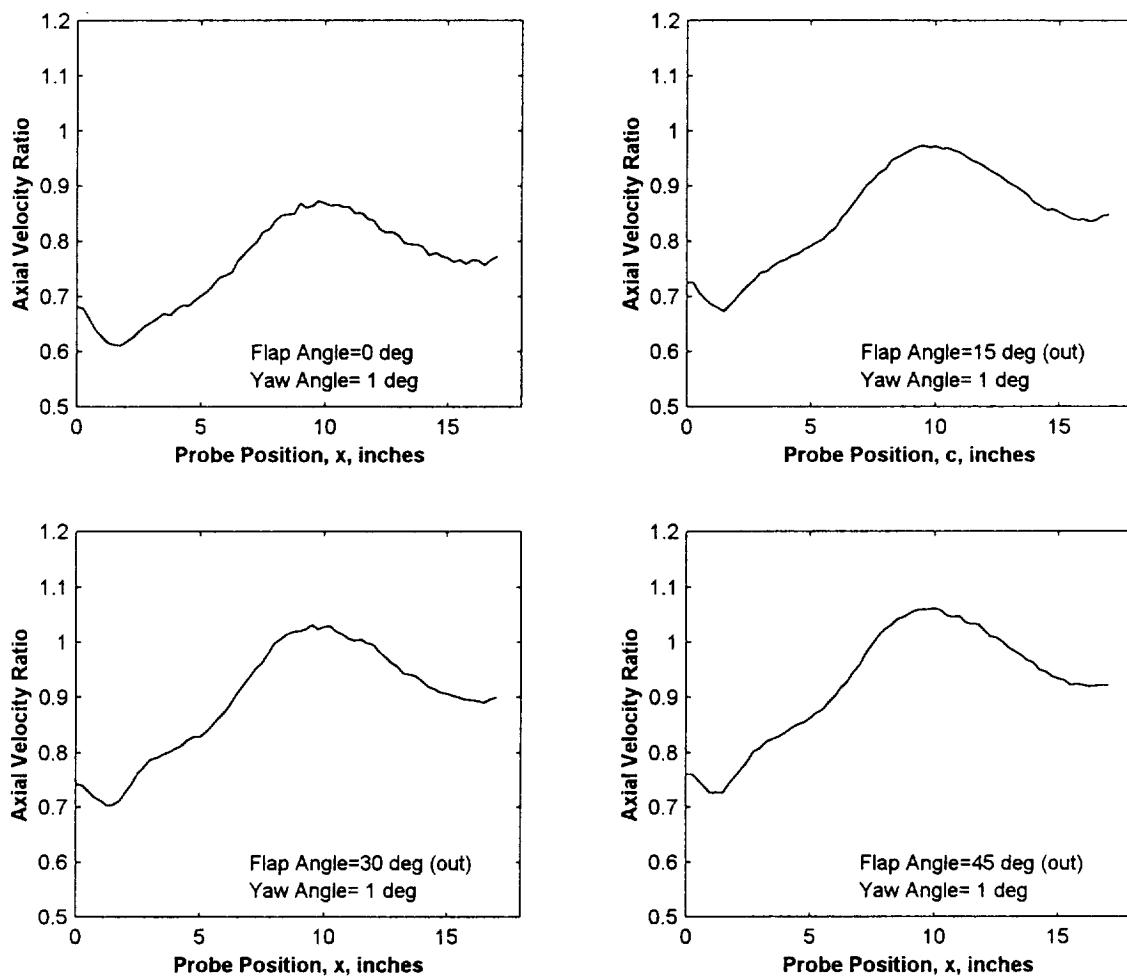


Figure A-5a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 1 deg
 Test #2, Test Section Velocity 220 ft/sec

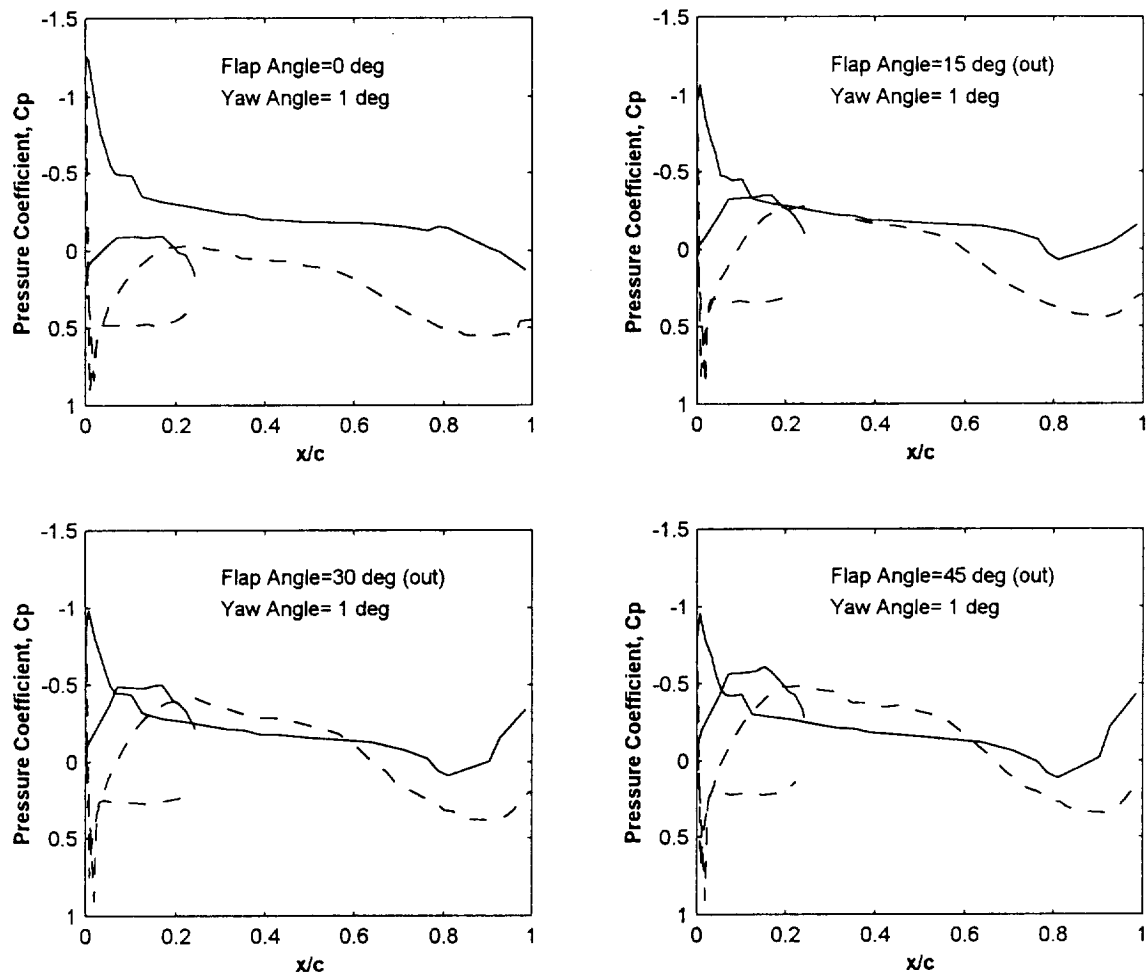


Figure A-6. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 1 deg
 Test #3, Test Section Velocity 220 ft/sec

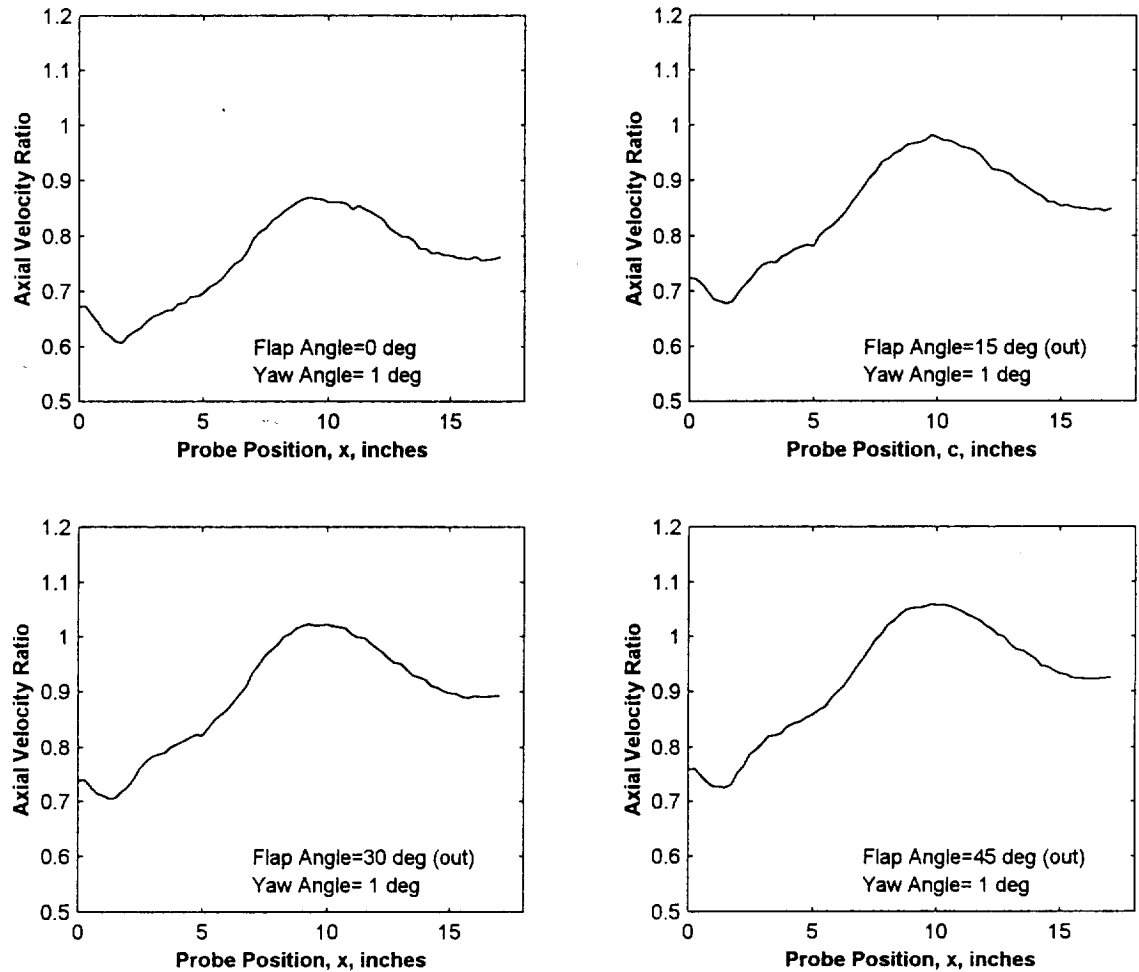


Figure A-6a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 1 deg
 Test #3, Test Section Velocity 220 ft/sec

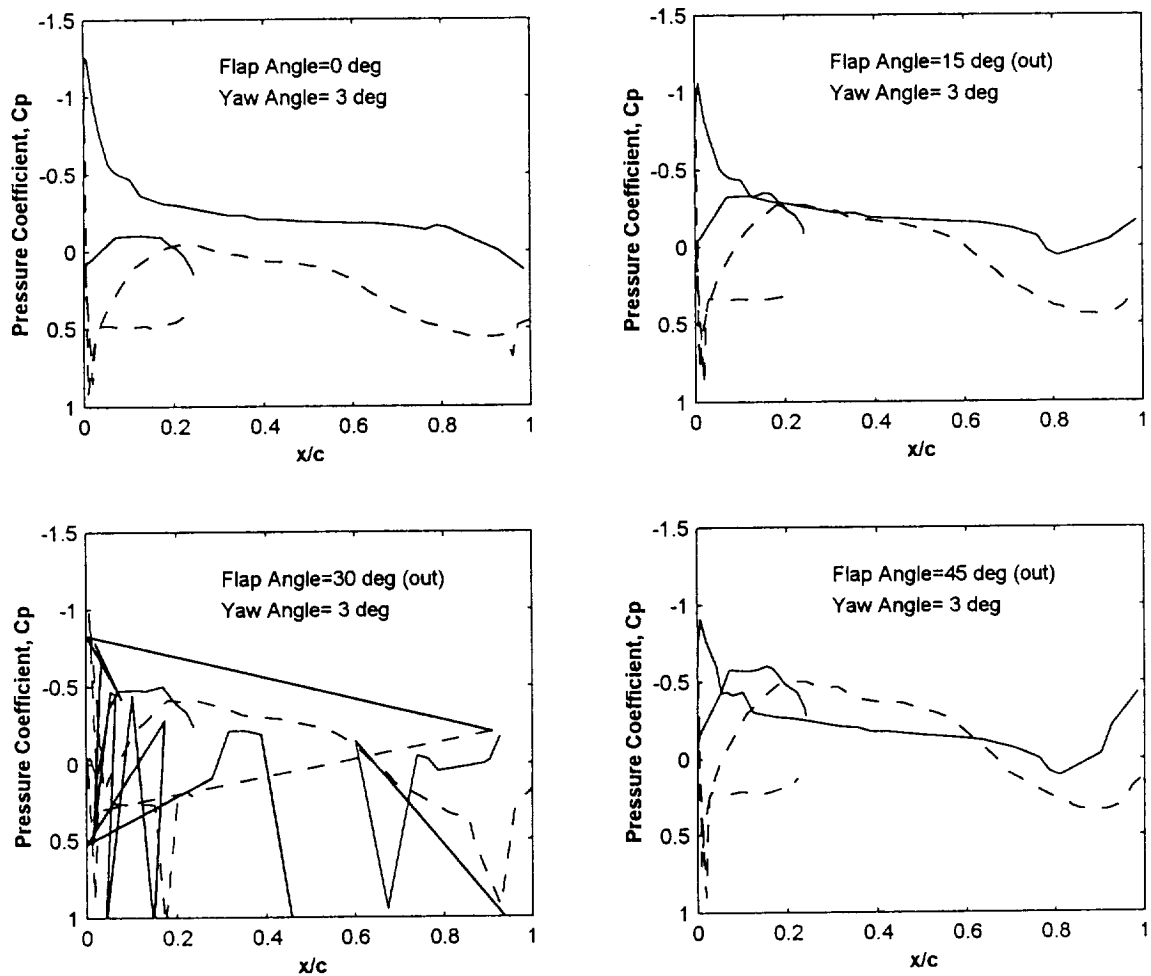


Figure A-7. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 3 deg
Test #1, Test Section Velocity 220 ft/sec

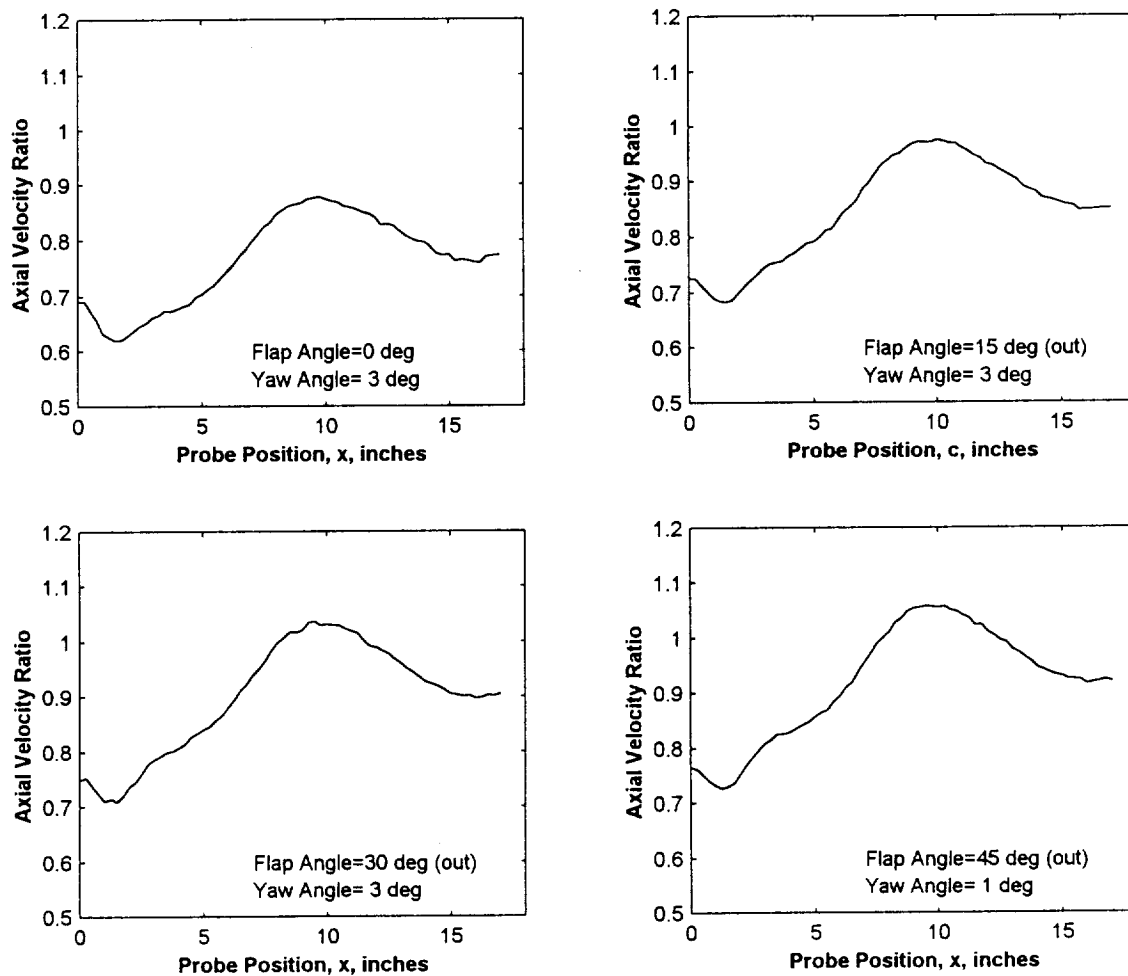


Figure A-7a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 3 deg
 Test #1, Test Section Velocity 220 ft/sec

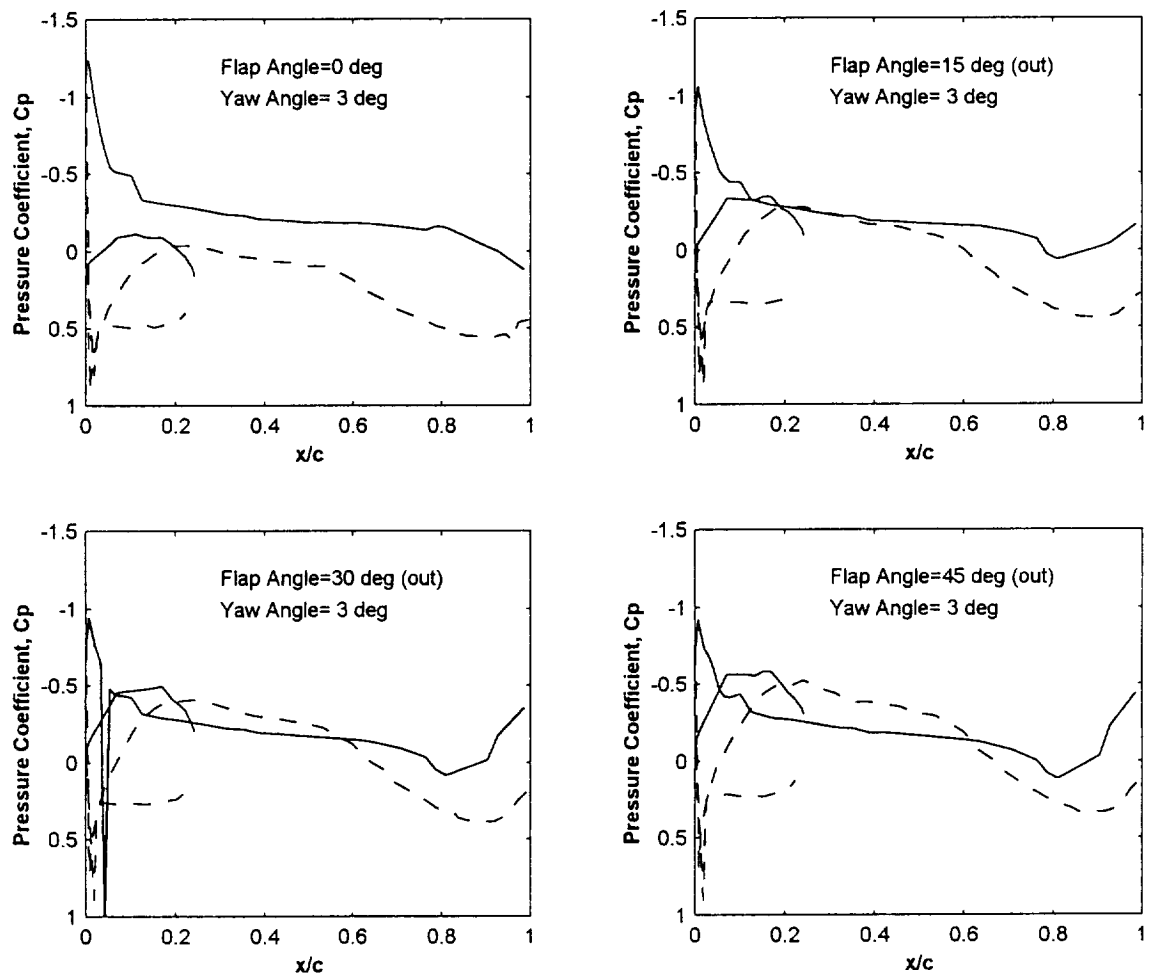


Figure A-8. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 3 deg
Test #2, Test Section Velocity 220 ft/sec

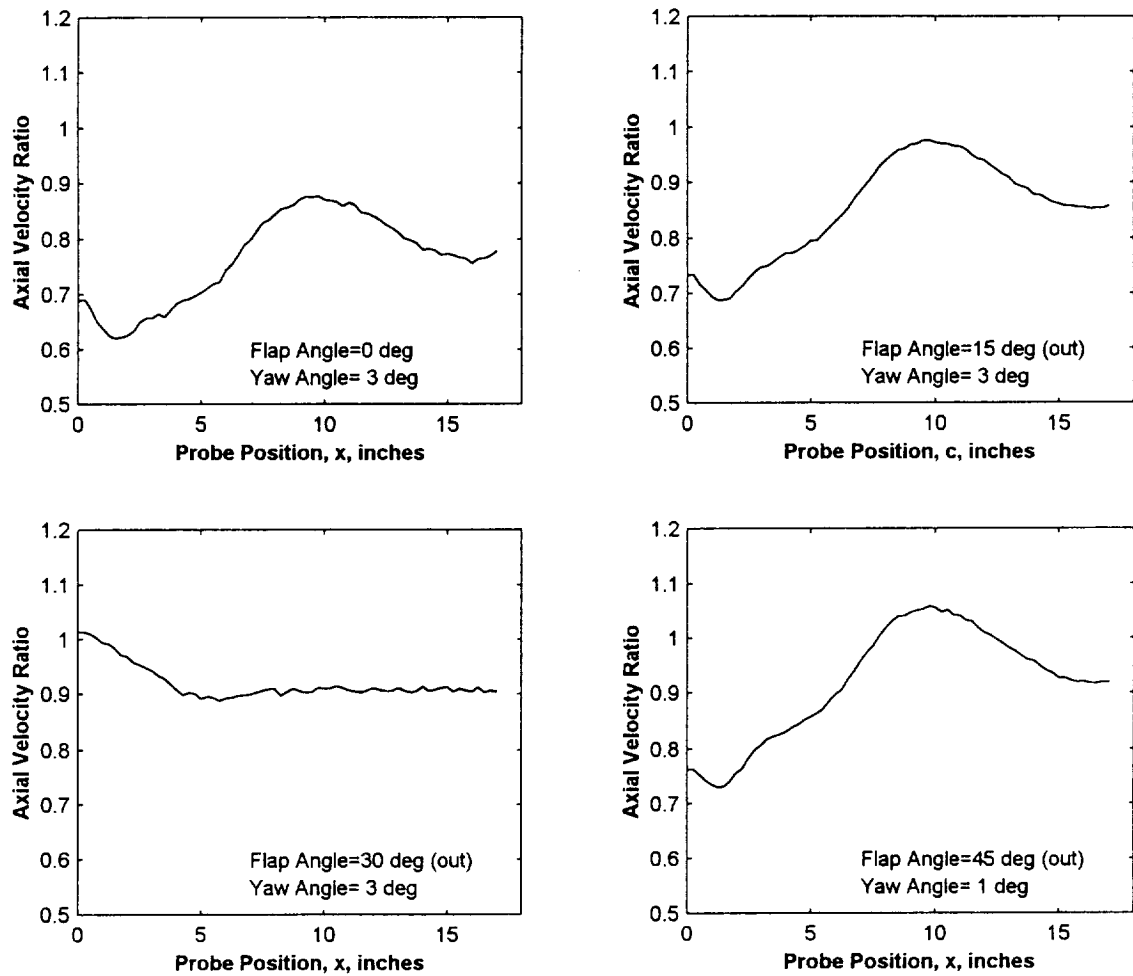


Figure A-8a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 3 deg
 Test #2, Test Section Velocity 220 ft/sec

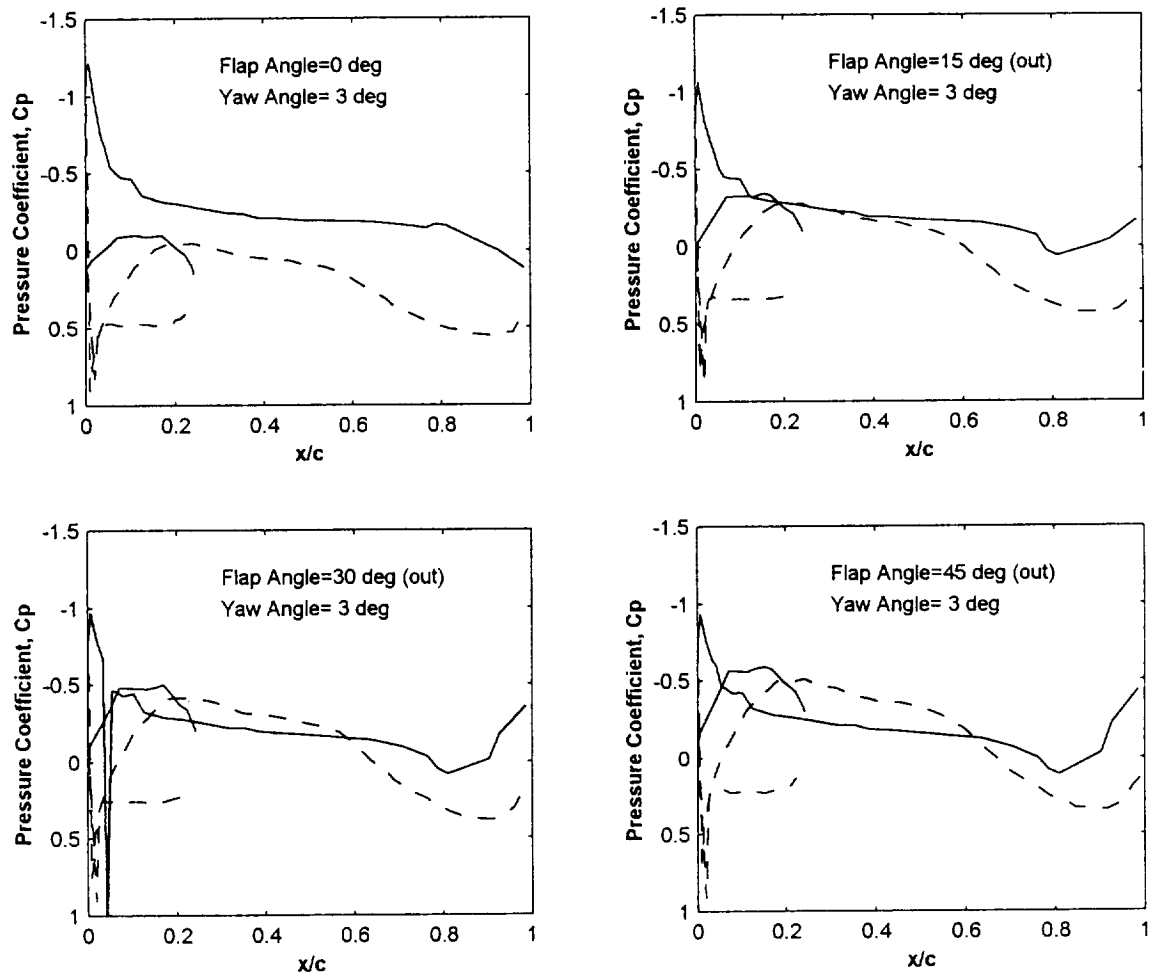


Figure A-9. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 3 deg
 Test #3, Test Section Velocity 220 ft/sec

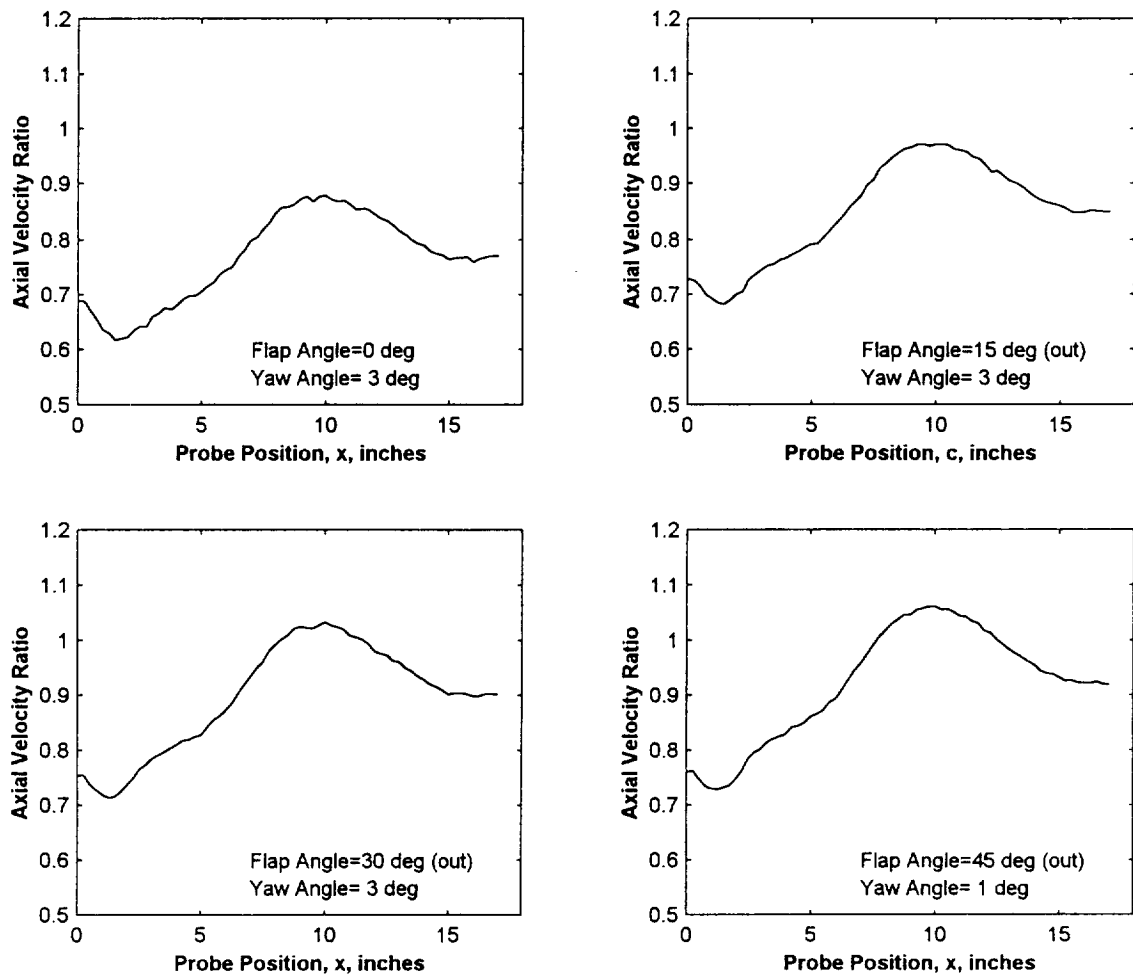


Figure A-9a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 3 deg
 Test #3, Test Section Velocity 220 ft/sec

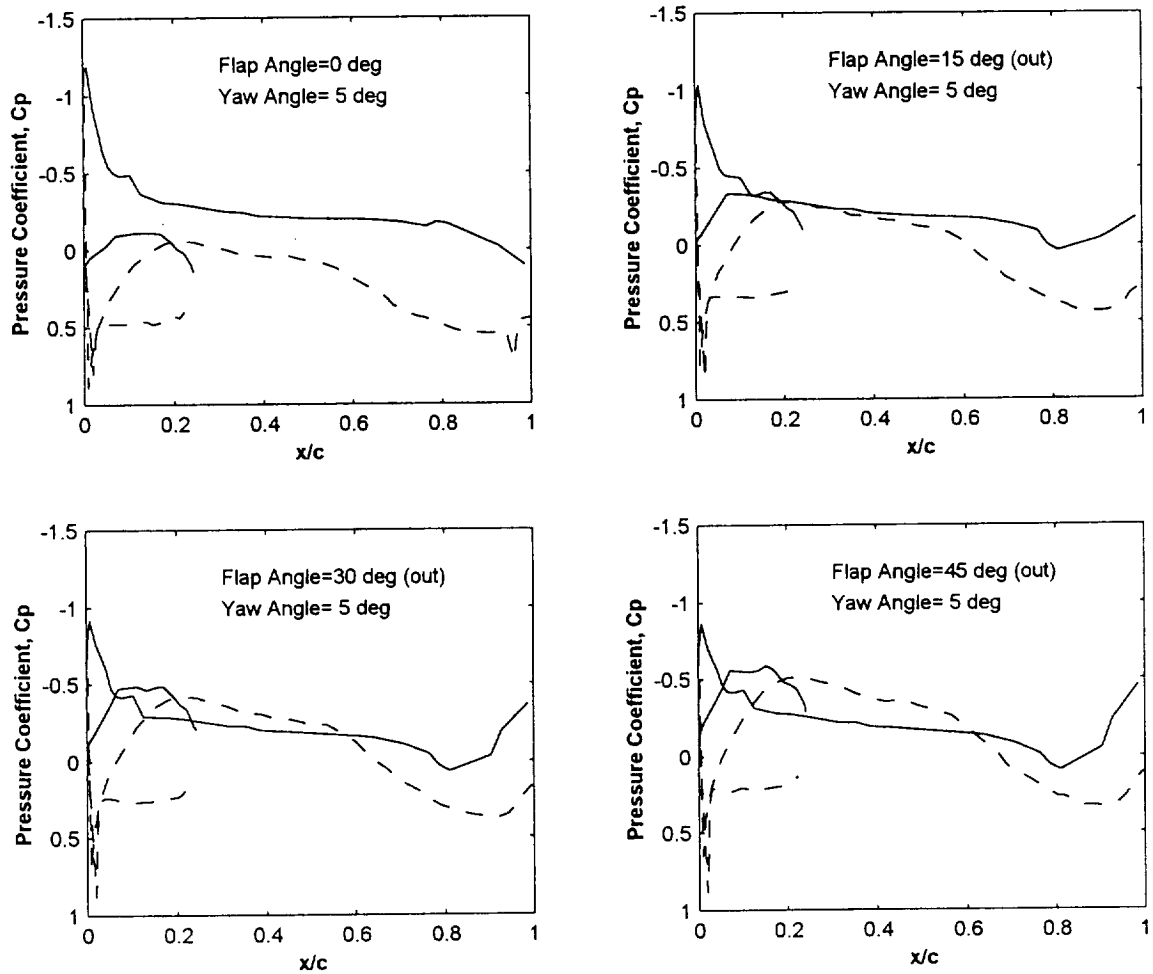


Figure A-10. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 5 deg
 Test #1, Test Section Velocity 220 ft/sec

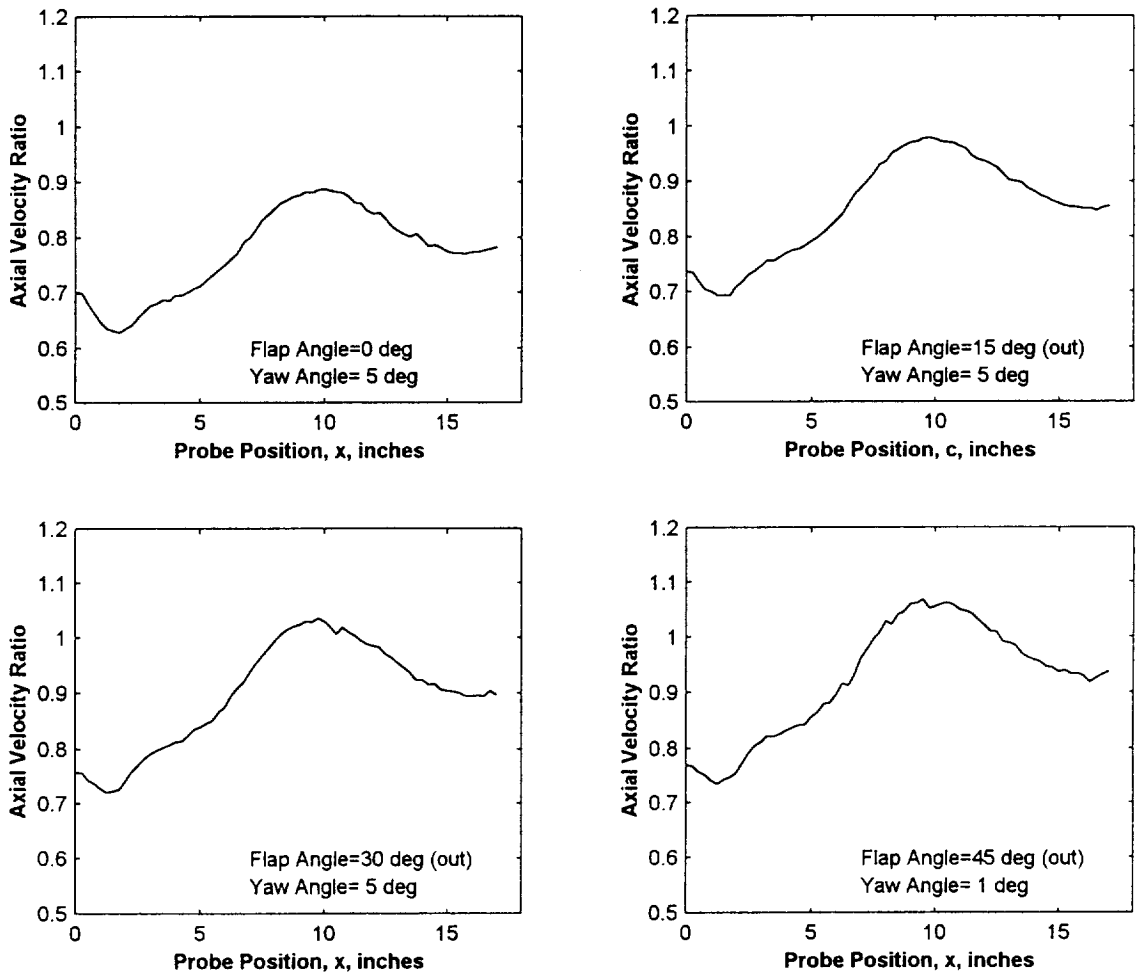


Figure A-10a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 5 deg
 Test #1, Test Section Velocity 220 ft/sec

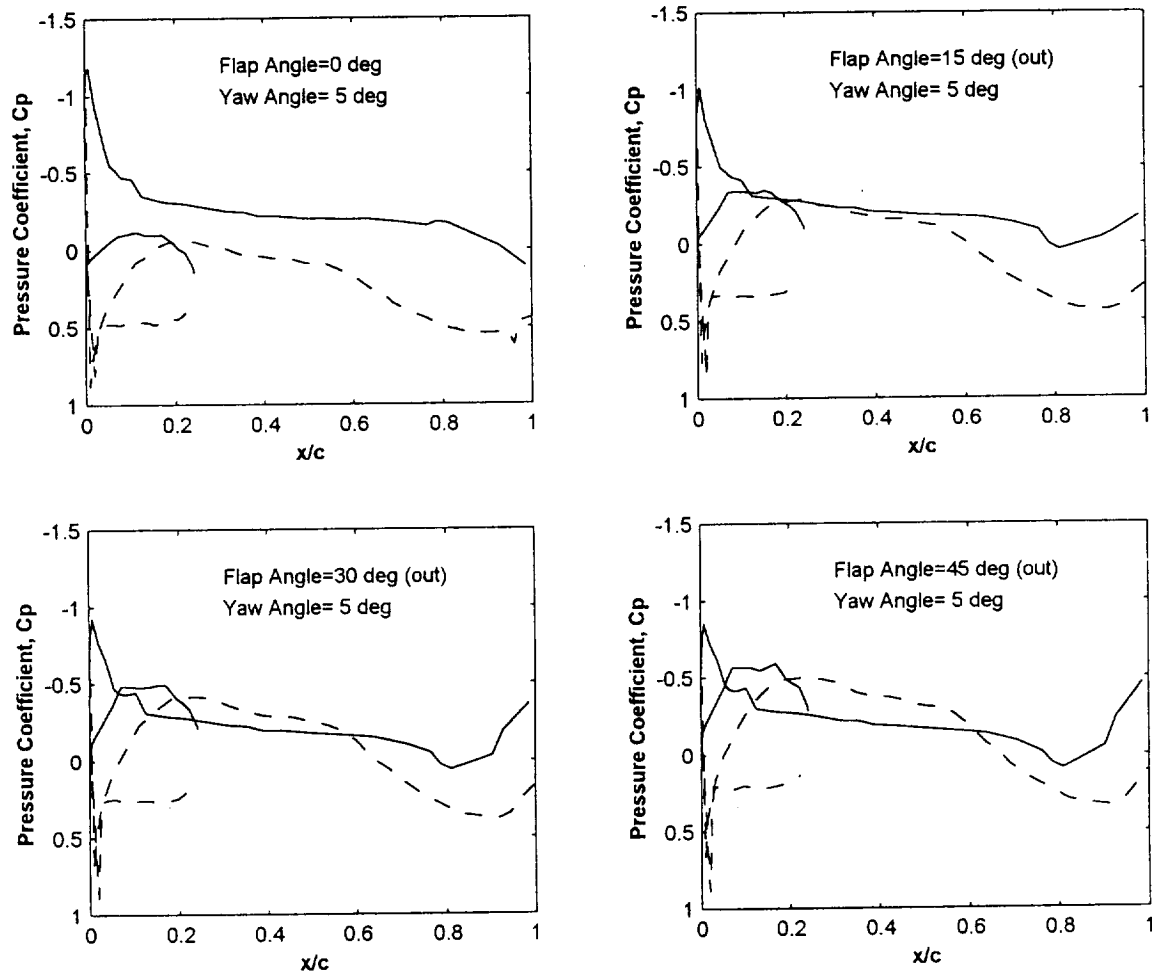


Figure A-11. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 5 deg
 Test #2, Test Section Velocity 220 ft/sec

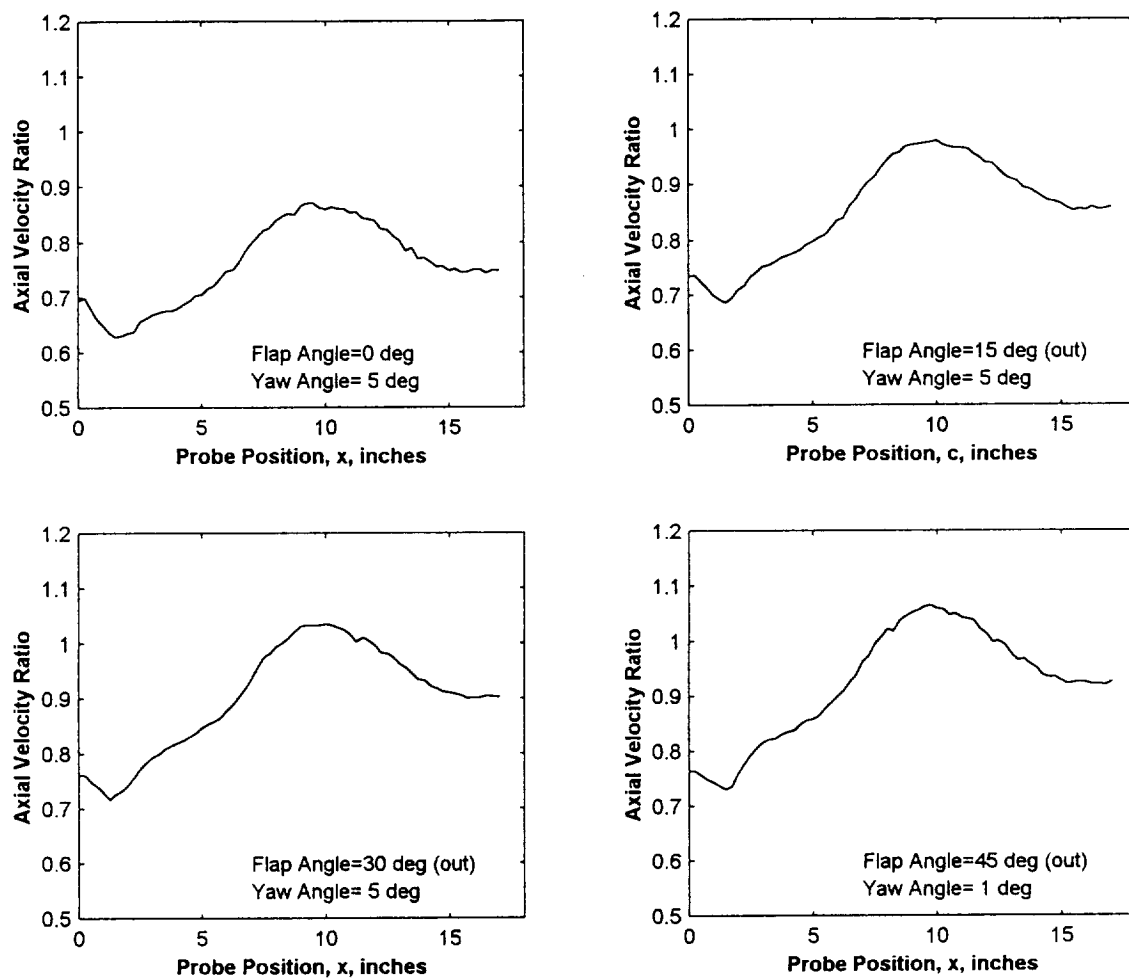


Figure A-11a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 5 deg
 Test #2, Test Section Velocity 220 ft/sec

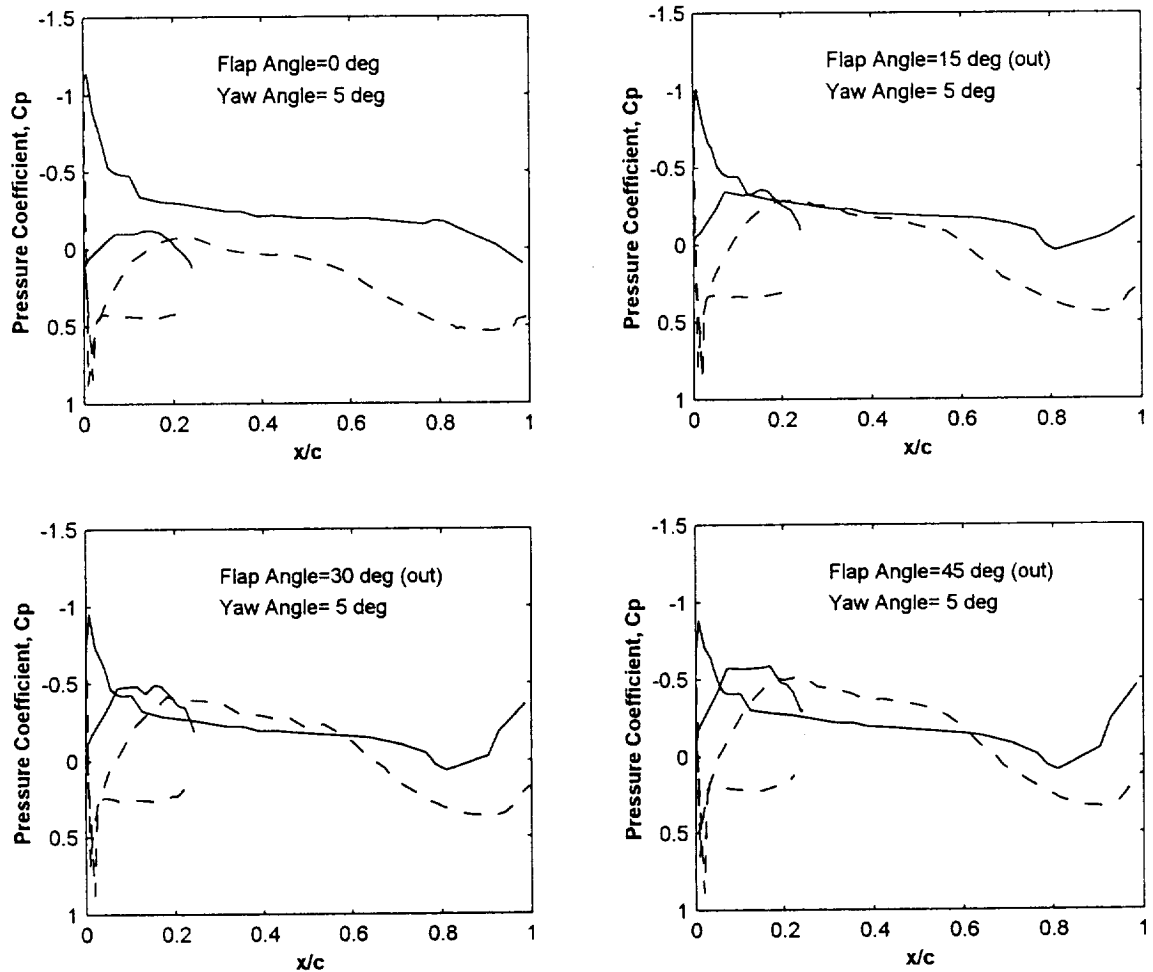


Figure A-12. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 5 deg
 Test #3, Test Section Velocity 220 ft/sec

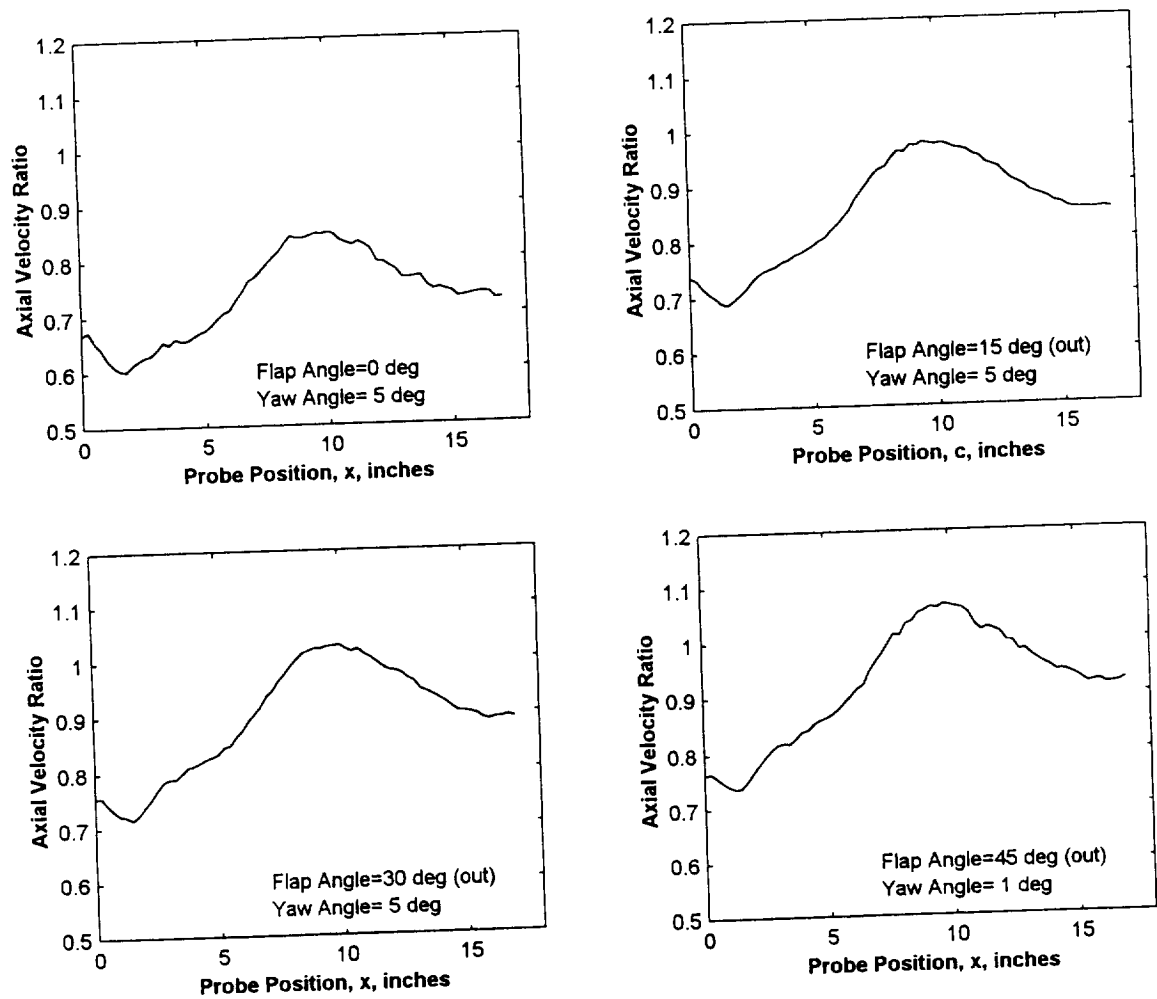


Figure A-12a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflections 0, 15, 30, 45 deg; Yaw Angle, 5 deg
 Test #3, Test Section Velocity 220 ft/sec

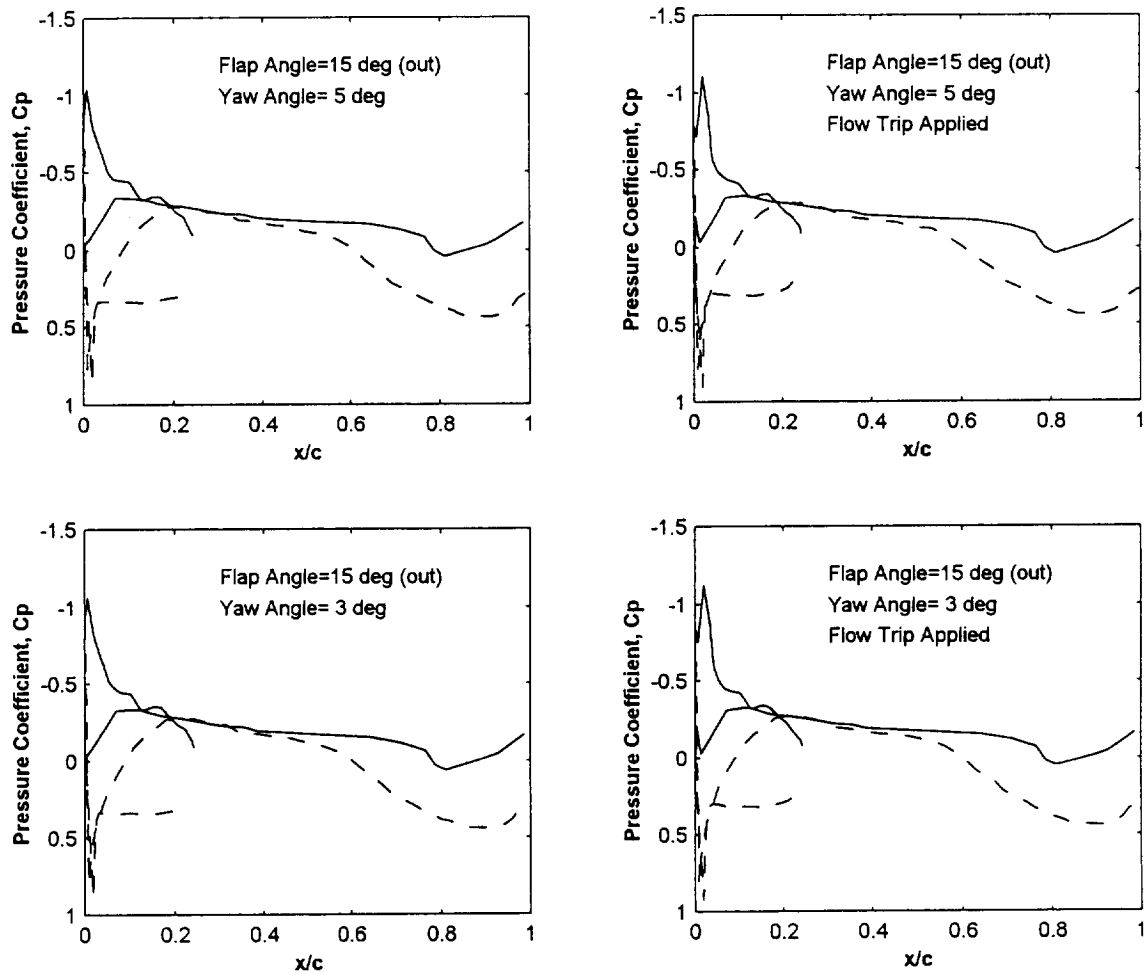


Figure A-13. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflection 15 deg; Yaw Angles 3, 5 deg
 Impact of Boundary Layer Trip
 Test #1, Test Section Velocity 220 ft/sec

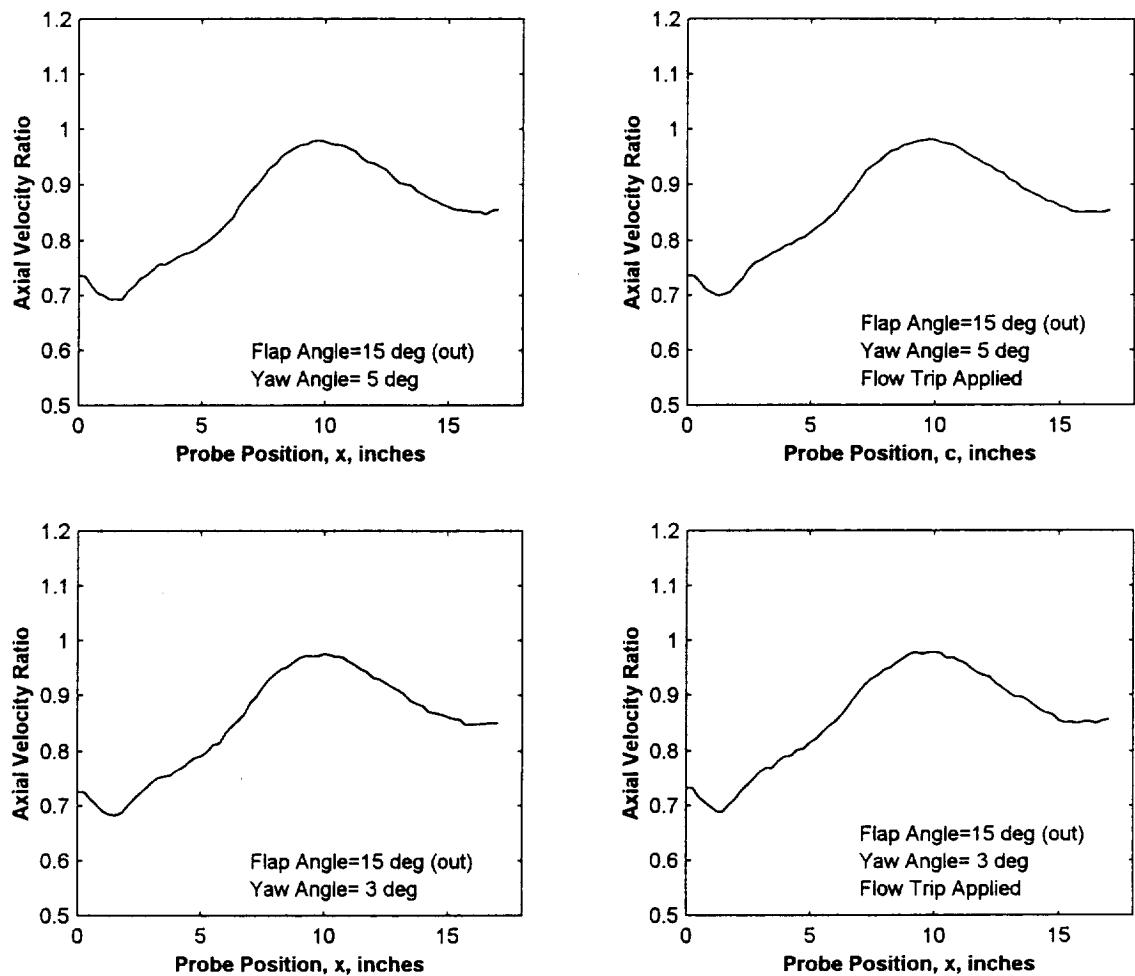


Figure A-13a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflection 15 deg; Yaw Angles 3, 5 deg
 Impact of Boundary Layer Trip
 Test #1, Test Section Velocity 220 ft/sec

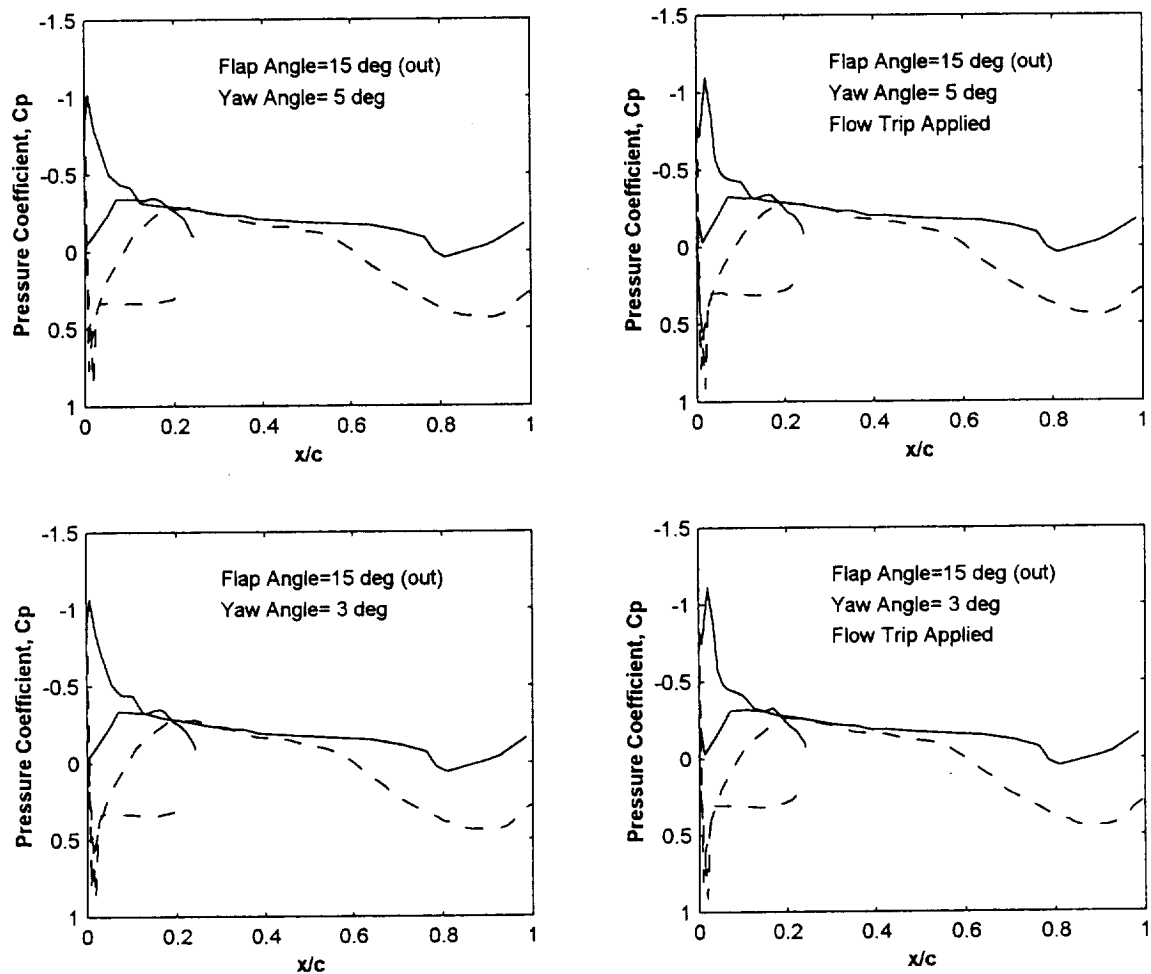


Figure A-14. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflection 15 deg; Yaw Angles 3, 5 deg
 Impact of Boundary Layer Trip
 Test #2, Test Section Velocity 220 ft/sec

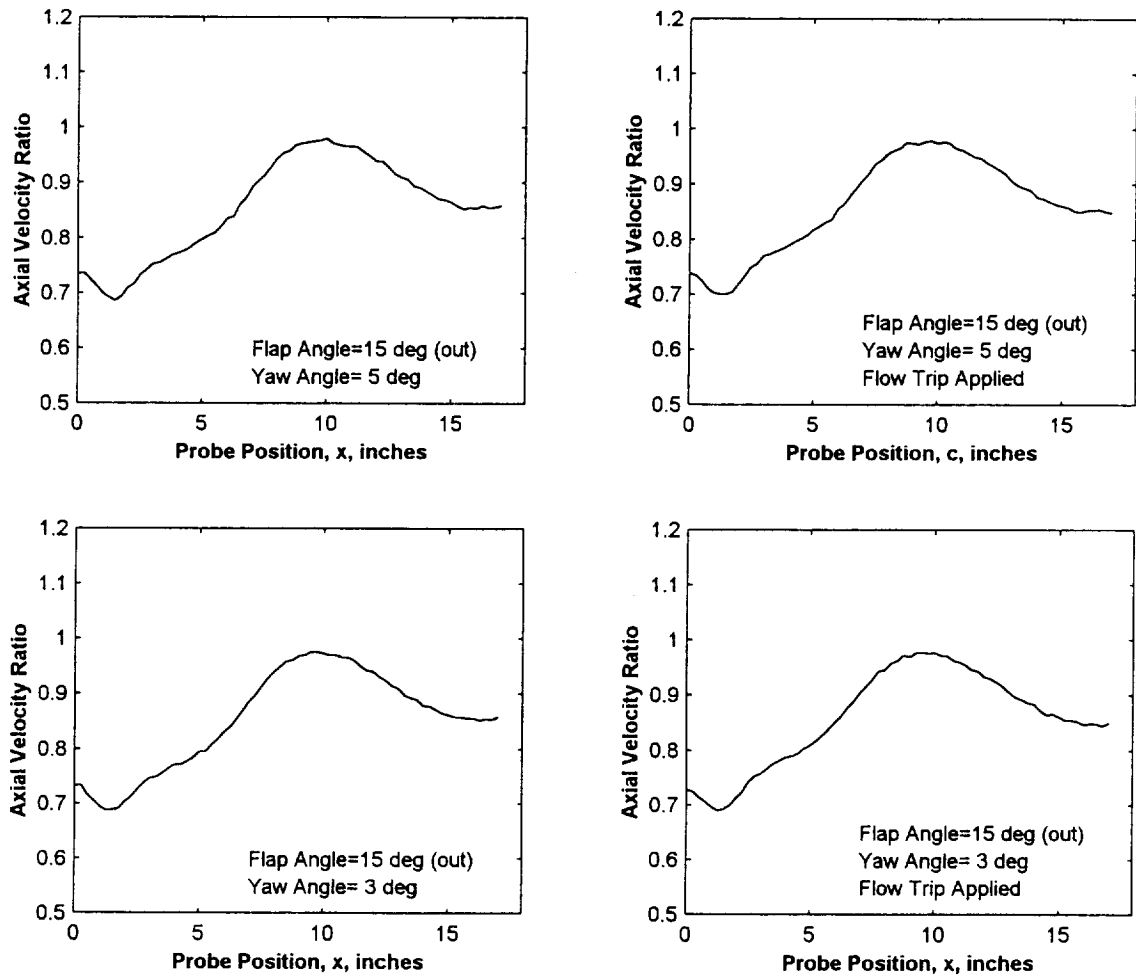


Figure A-14a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflection 15 deg; Yaw Angles 3, 5 deg
 Impact of Boundary Layer Trip
 Test #2, Test Section Velocity 220 ft/sec

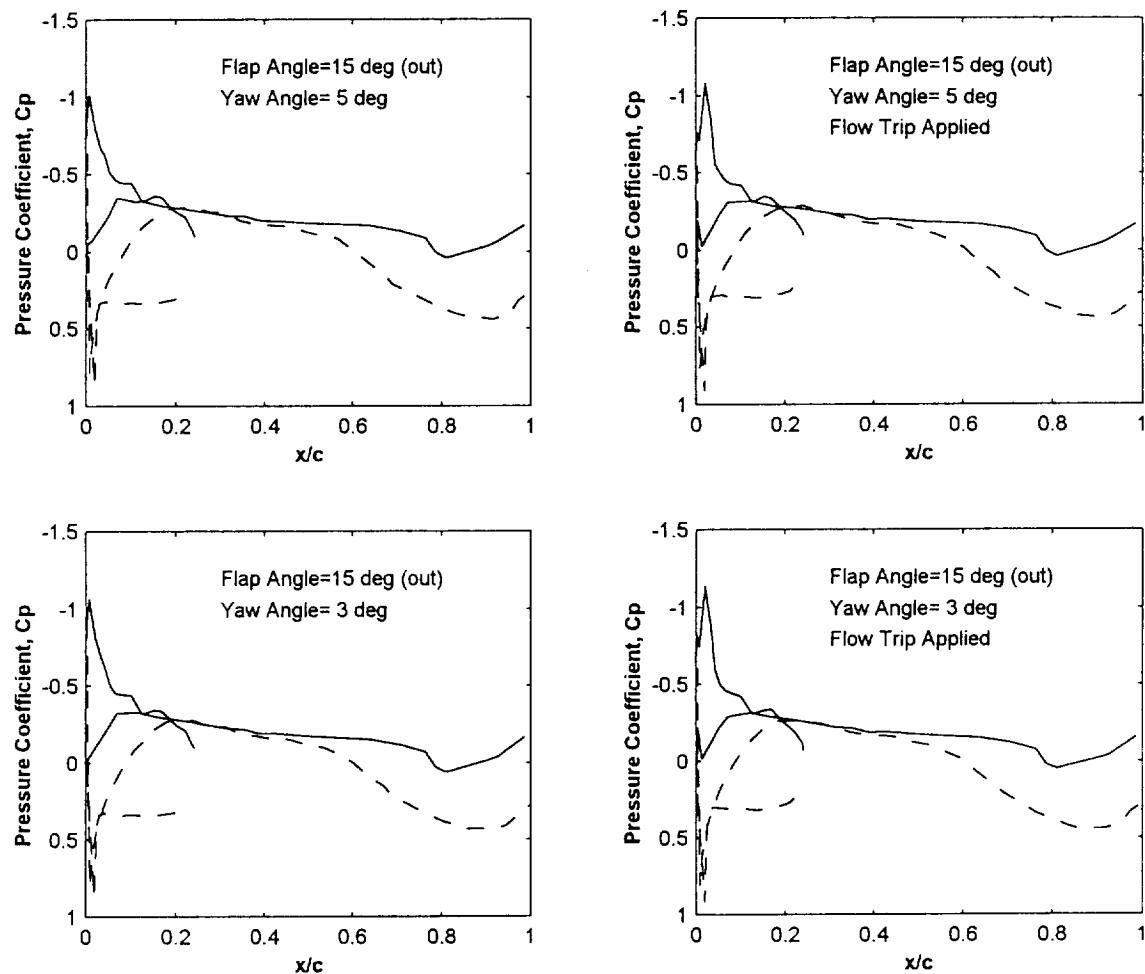


Figure A-15. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside Flap Deflection 15 deg; Yaw Angles 3, 5 deg
 Impact of Boundary Layer Trip
 Test #3, Test Section Velocity 220 ft/sec

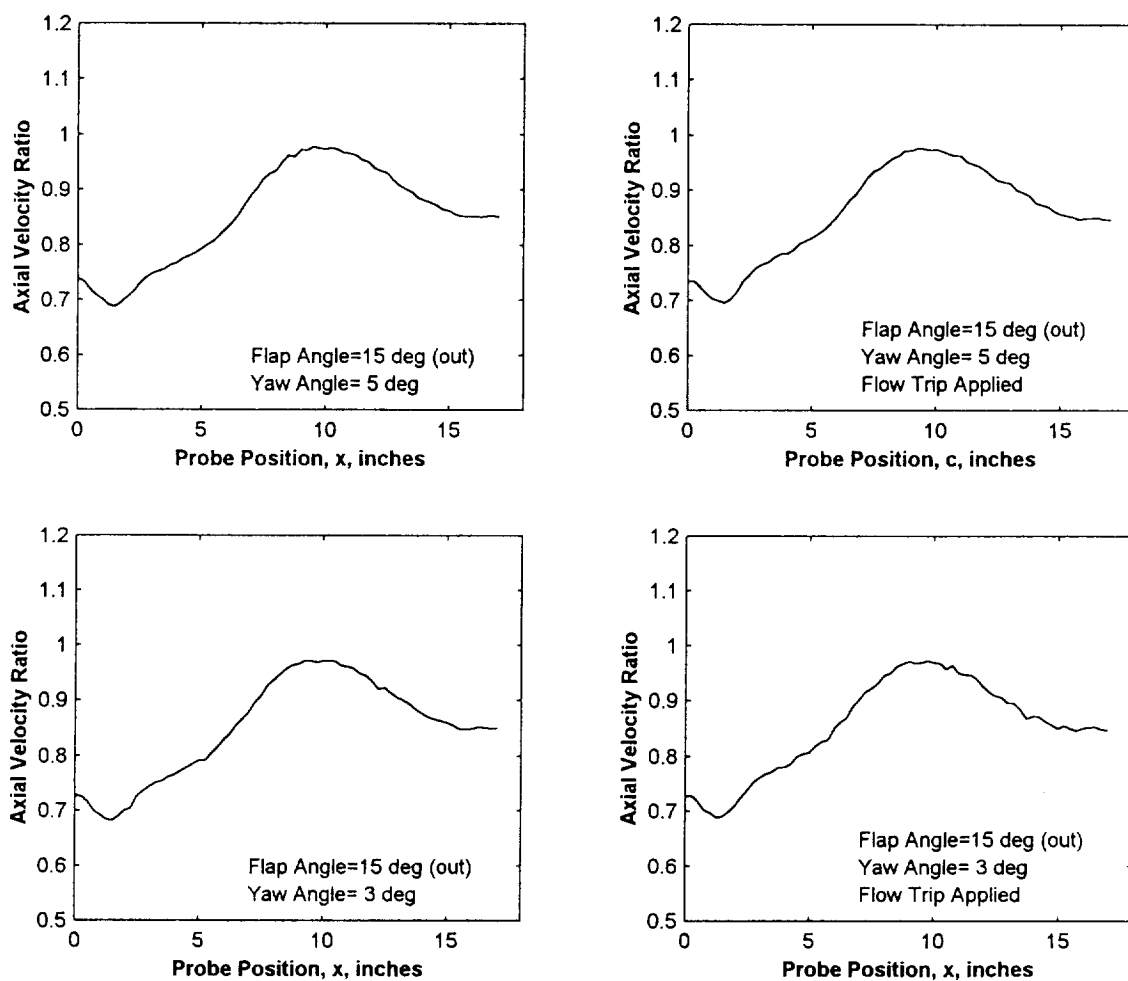


Figure A-15a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside Flap Deflection 15 deg; Yaw Angles 3, 5 deg
 Impact of Boundary Layer Trip
 Test #3, Test Section Velocity 220 ft/sec

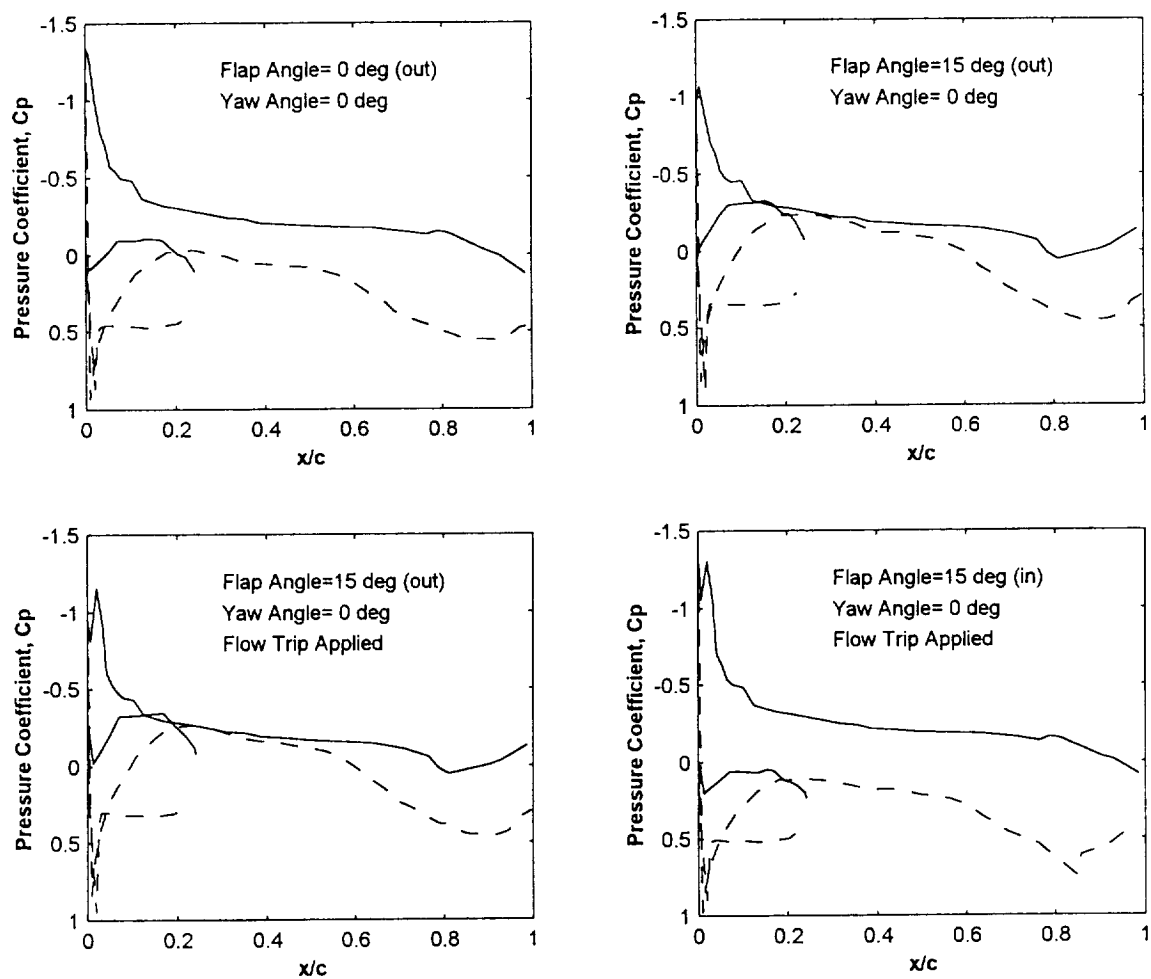


Figure A-16. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside & Inside Flap Deflection 15 deg; Yaw Angle 0 deg
 Impact of Boundary Layer Trip
 Test #1, Test Section Velocity 220 ft/sec

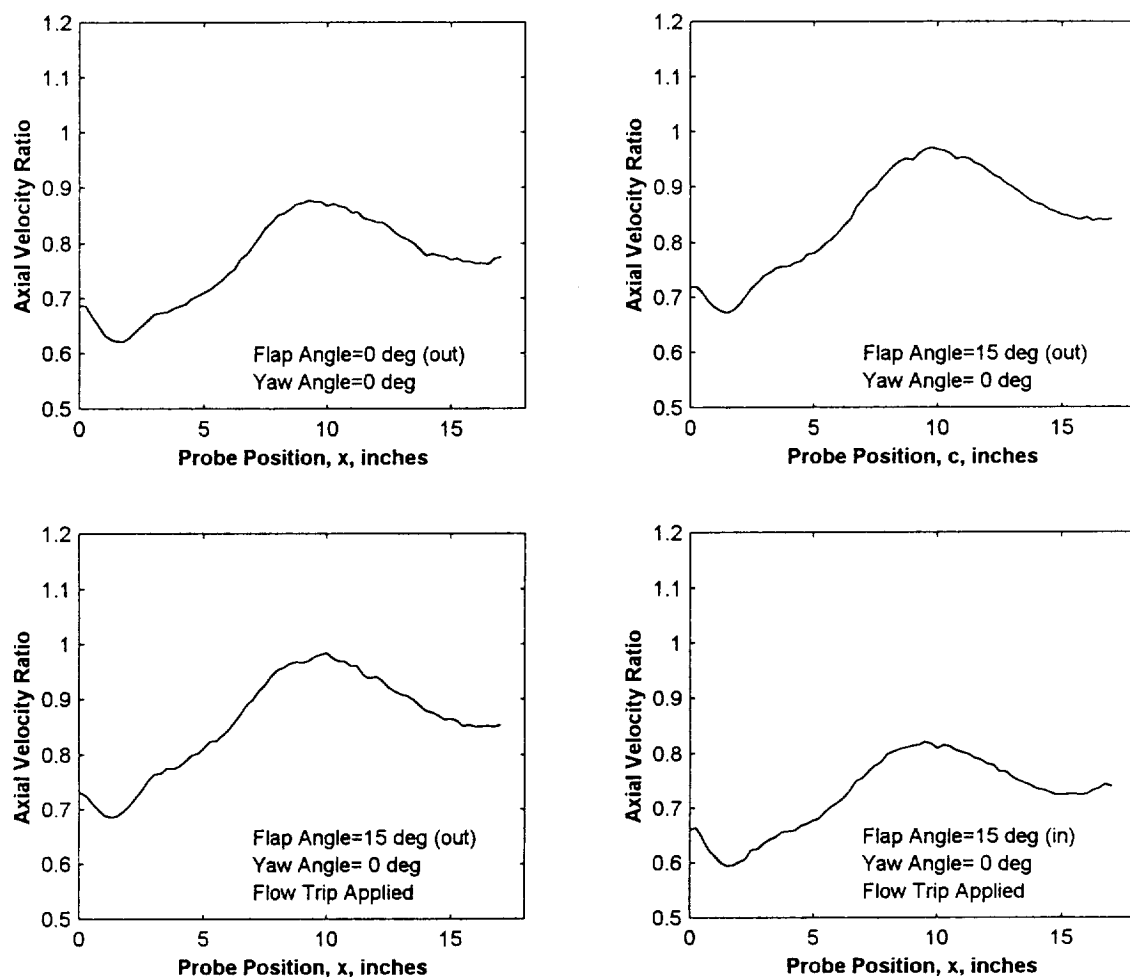


Figure A-16a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside & Inside Flap Deflection 15 deg; Yaw Angle 0 deg
 Impact of Boundary Layer Trip
 Test #1, Test Section Velocity 220 ft/sec

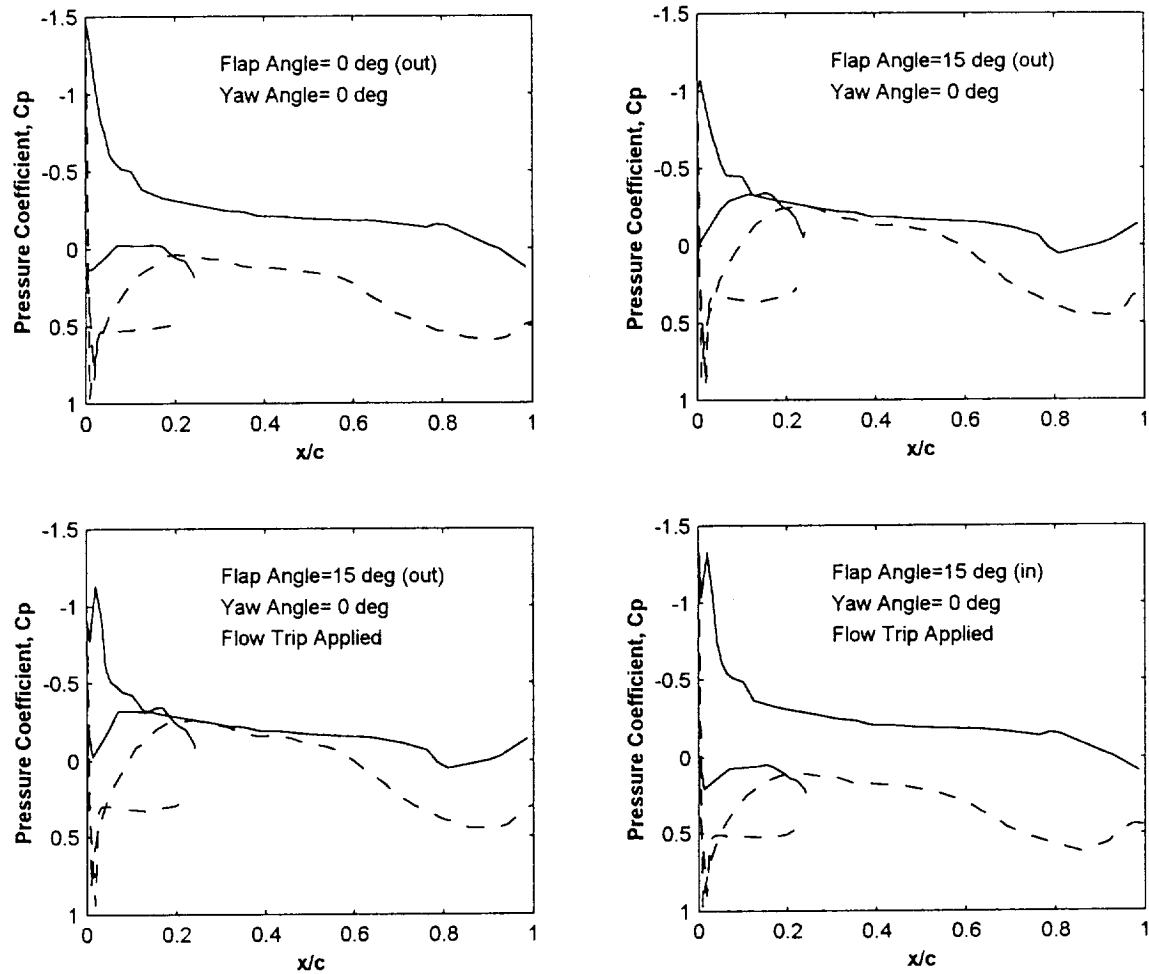


Figure A-17. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside & Inside Flap Deflection 15 deg; Yaw Angle 0 deg
 Impact of Boundary Layer Trip
 Test #2, Test Section Velocity 220 ft/sec

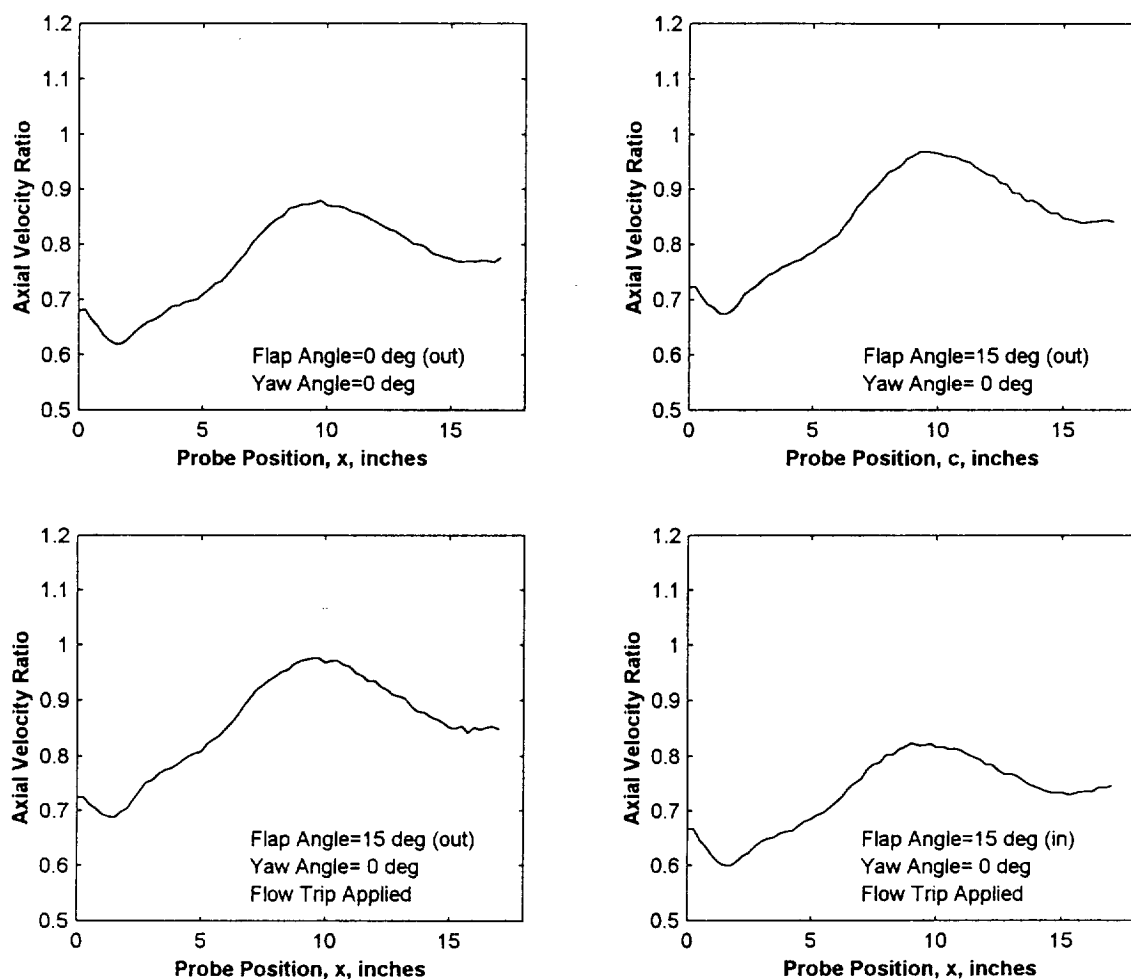


Figure A-17a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside & Inside Flap Deflection 15 deg; Yaw Angle 0 deg
 Impact of Boundary Layer Trip
 Test #2, Test Section Velocity 220 ft/sec

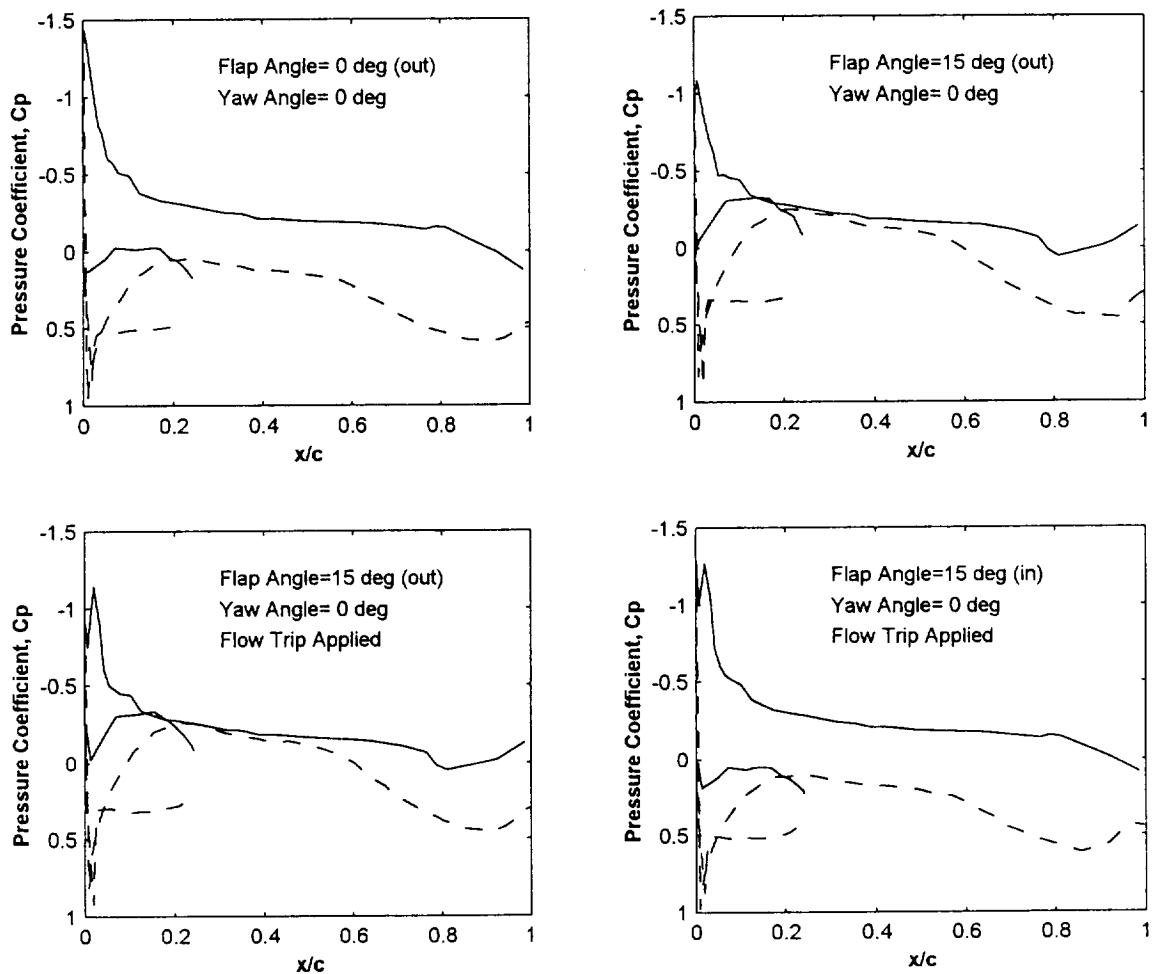


Figure A-18. Probe Surface Pressure Distribution, Inner & Outer Annular Surfaces
 Outside & Inside Flap Deflection 15 deg; Yaw Angle 0 deg
 Impact of Boundary Layer Trip
 Test #3, Test Section Velocity 220 ft/sec

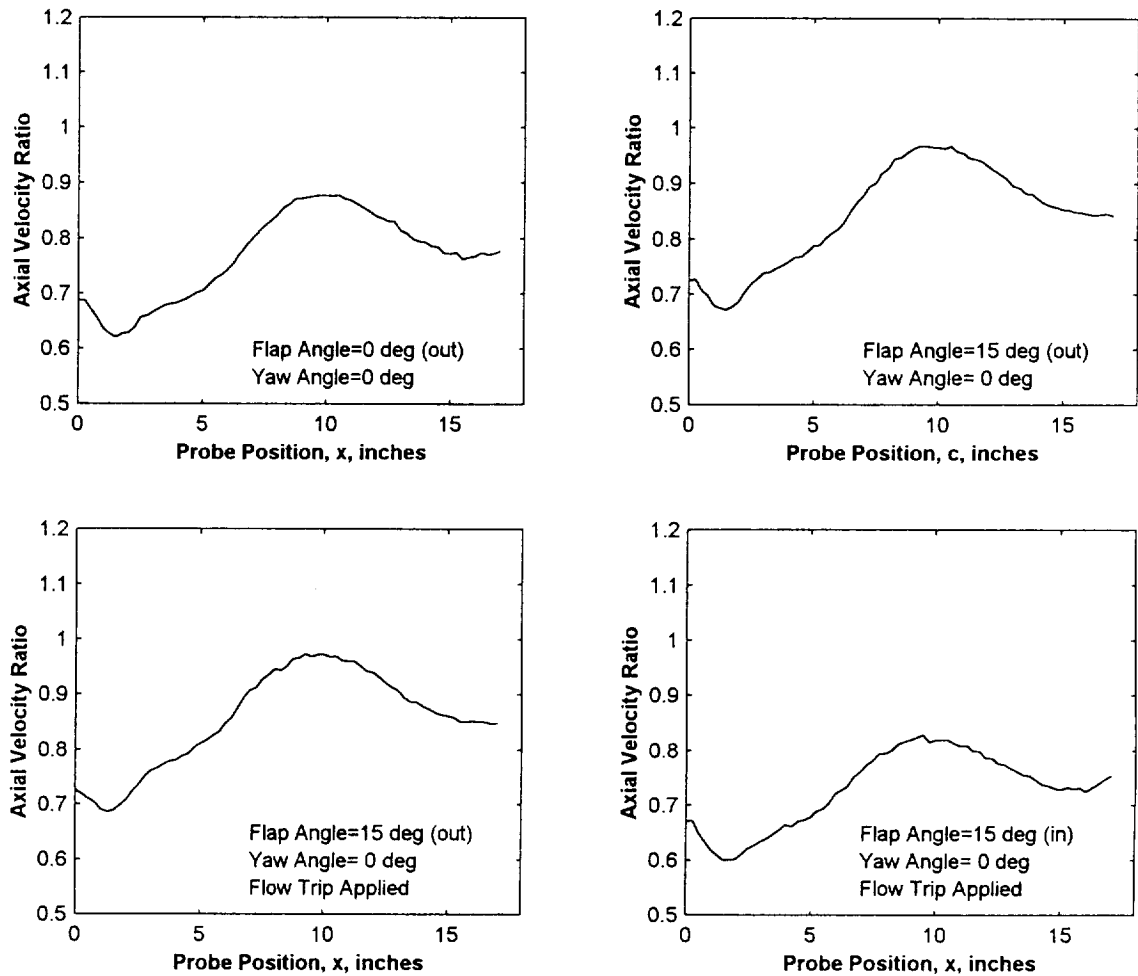


Figure A-18a. Probe Centerline Velocity Ratio (Local Velocity)/(Test Section Velocity)
 Outside & Inside Flap Deflection 15 deg; Yaw Angle 0 deg
 Impact of Boundary Layer Trip
 Test #3, Test Section Velocity 220 ft/sec